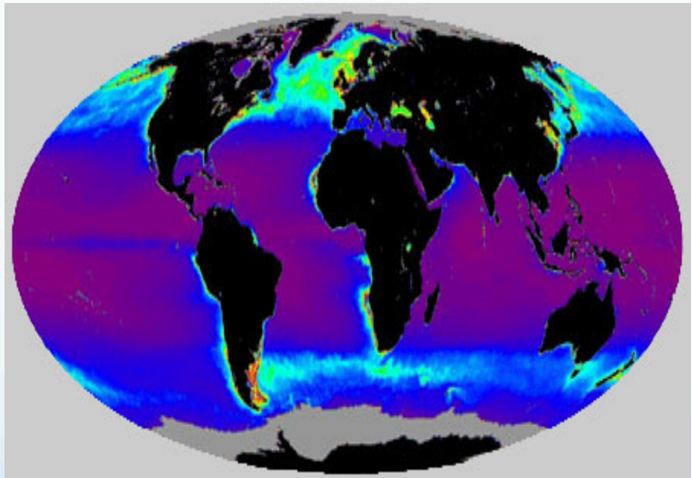
Carbon cycle: what can we learn from atmospheric measurements of Greenhouse gases?

OUTLINE

- **Present carbon cycle**
- Inferring surface fluxes from atmospheric observations
- Scales and constraints

CO_2 natural exchanges

Marine primary production



Outgasing
90 ± 20

Absorbtion
90 ± 20

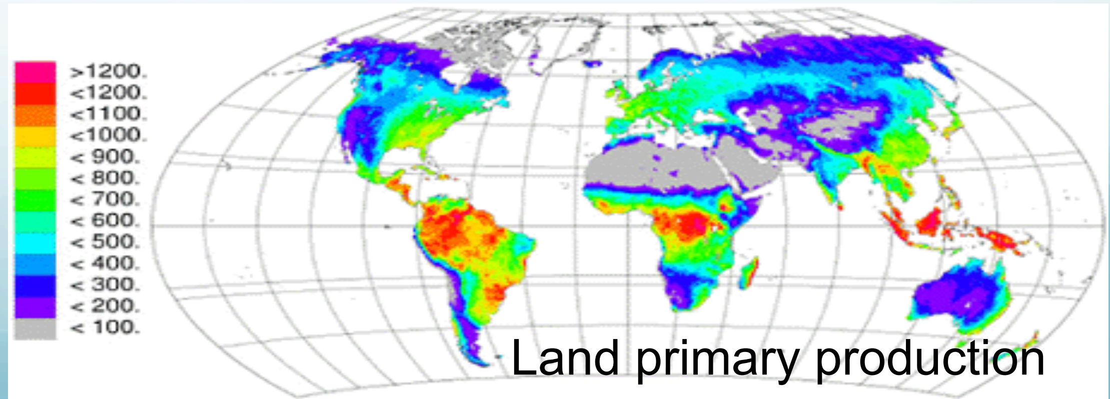
Erosion

Respiration
120 ± 30

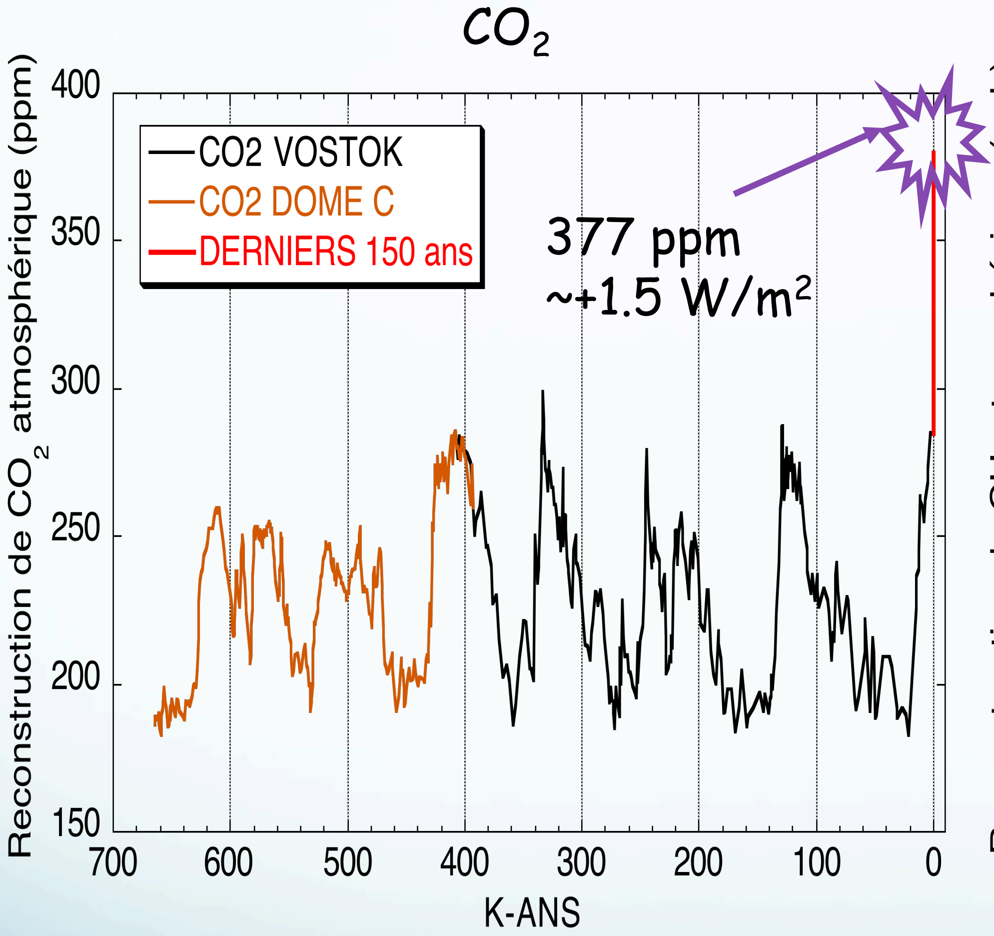
Photosynthesis
120 ± 30

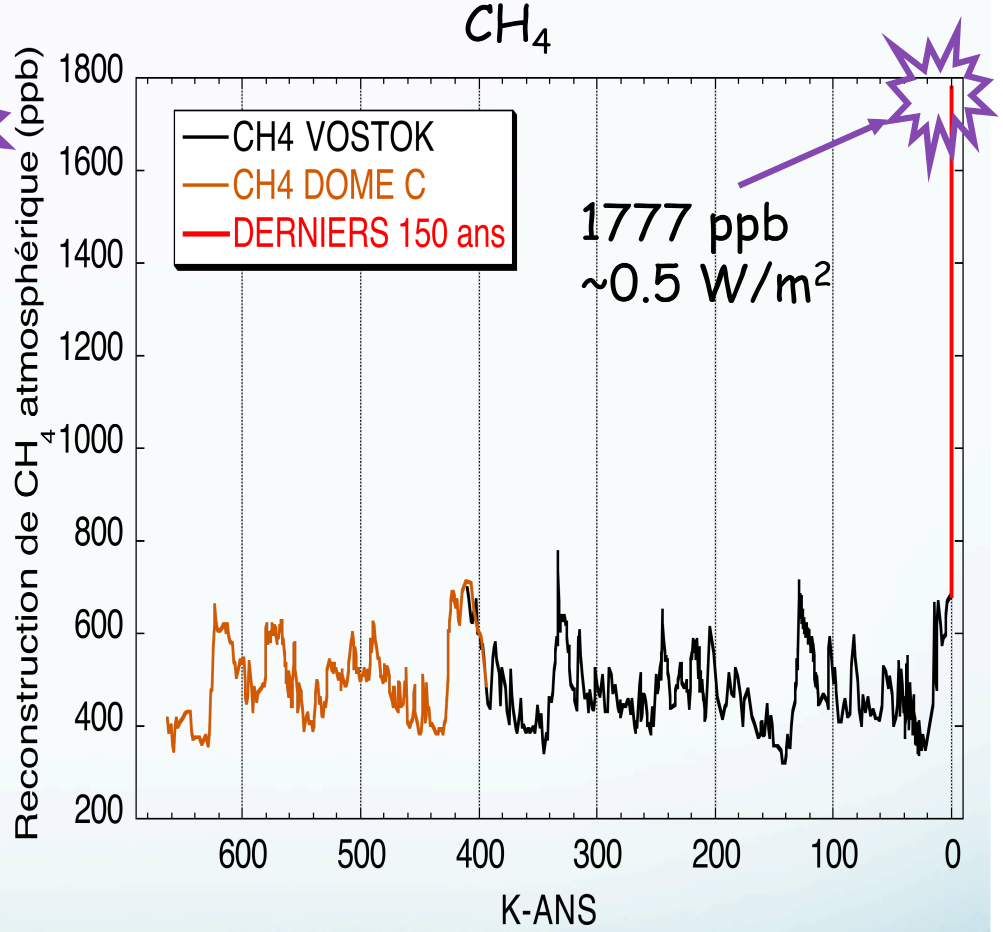
0.6

Annual fluxes for the 1990s
Source : IPCC-TAR



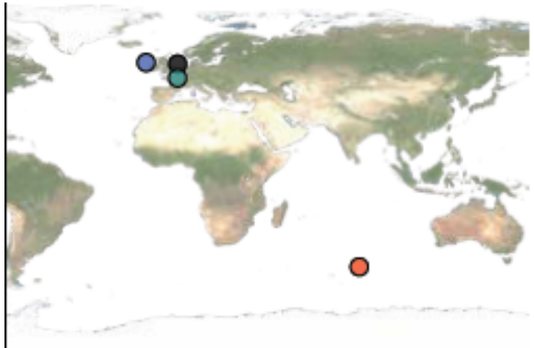
A fast increase of greehouse gas concentrations





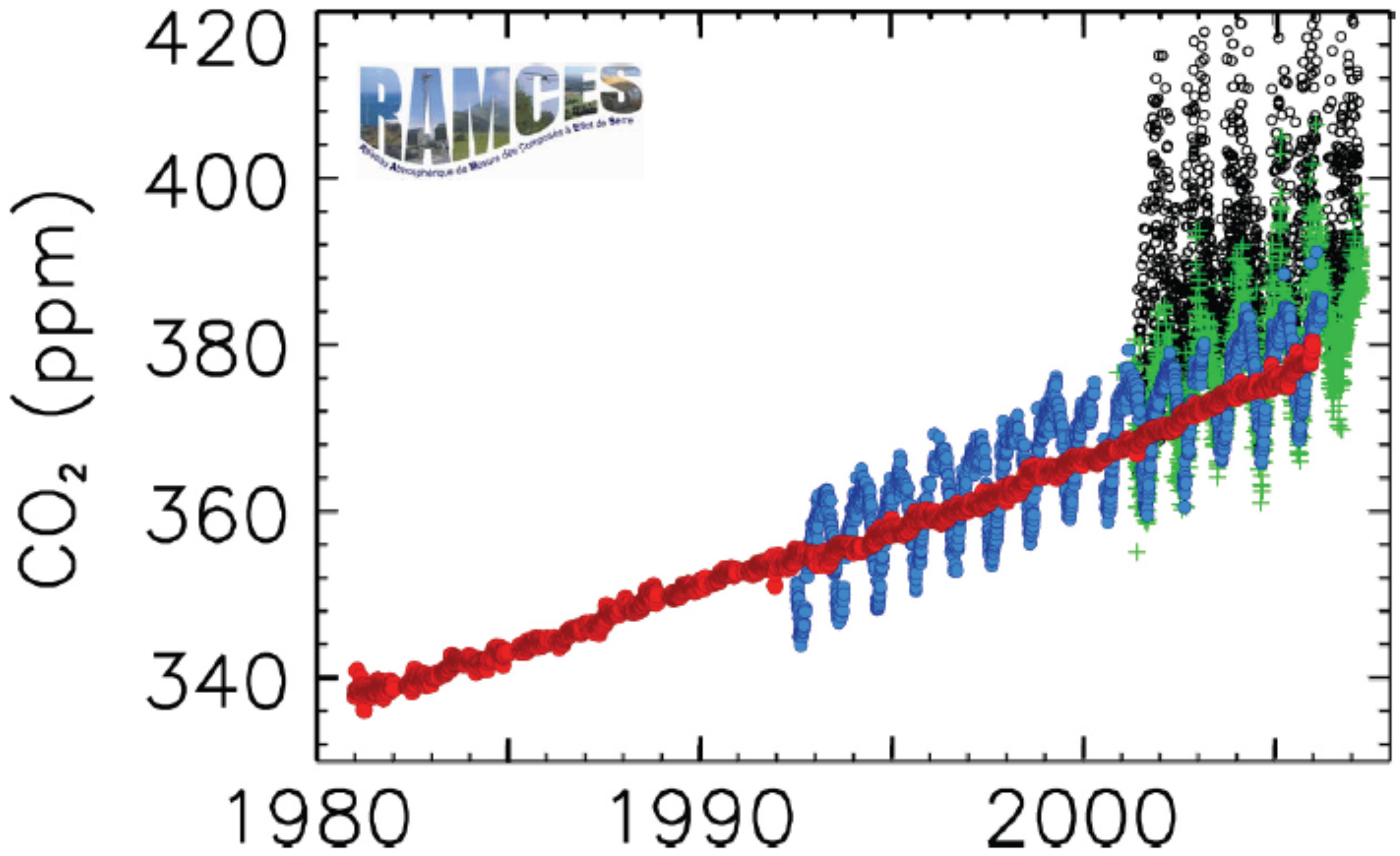
Petit et al, 1999
Siegenthaler et al., 2005
Parrenin et al., 2004

Petit et al, 1999
Spahni et al., 2005
Parrenin et al., 2004



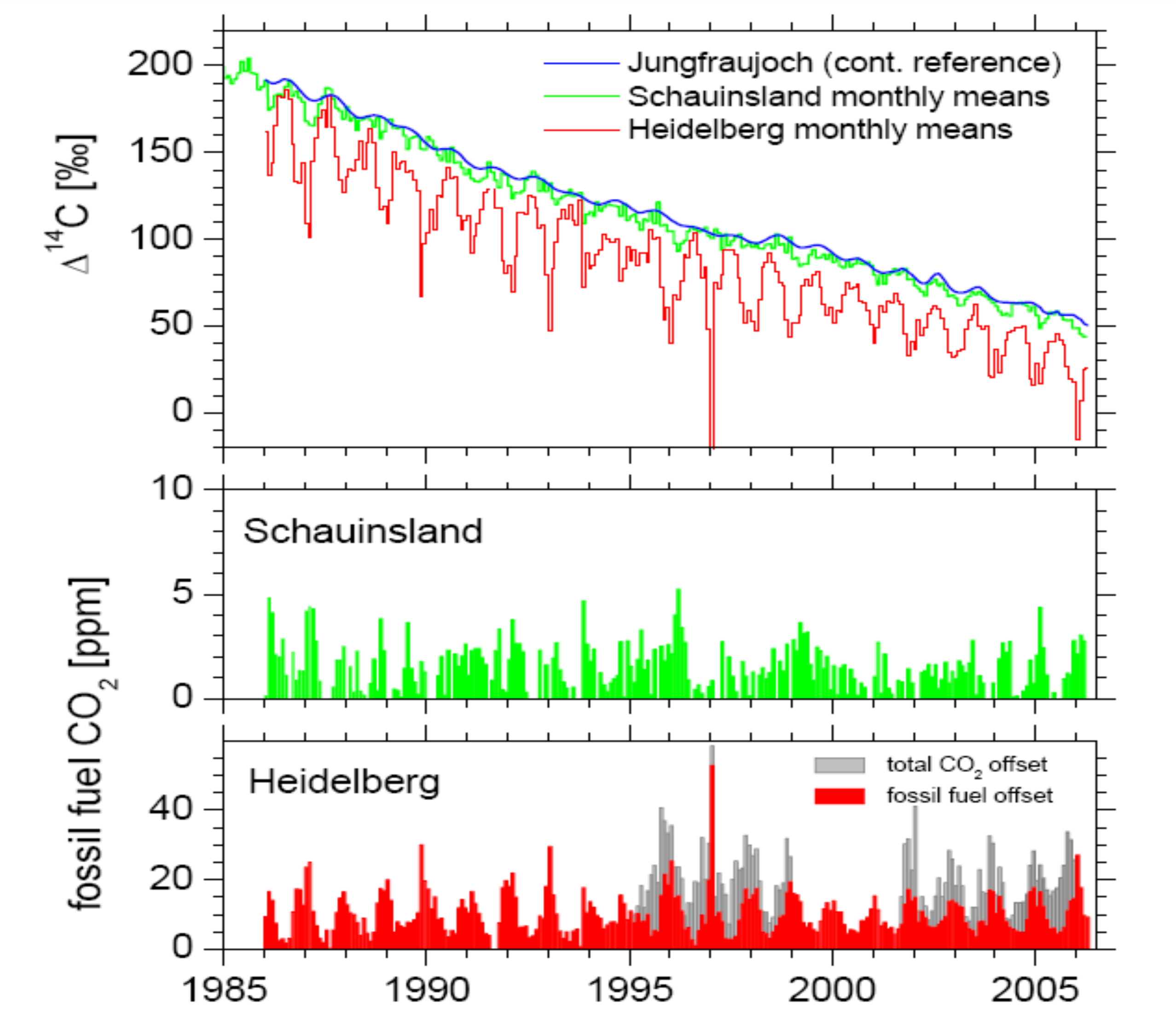
CO_2 monitoring from remote to urban site

French network for Greenhouse gases (LSCE)



Typical measurement precision = ±0.3 ppm

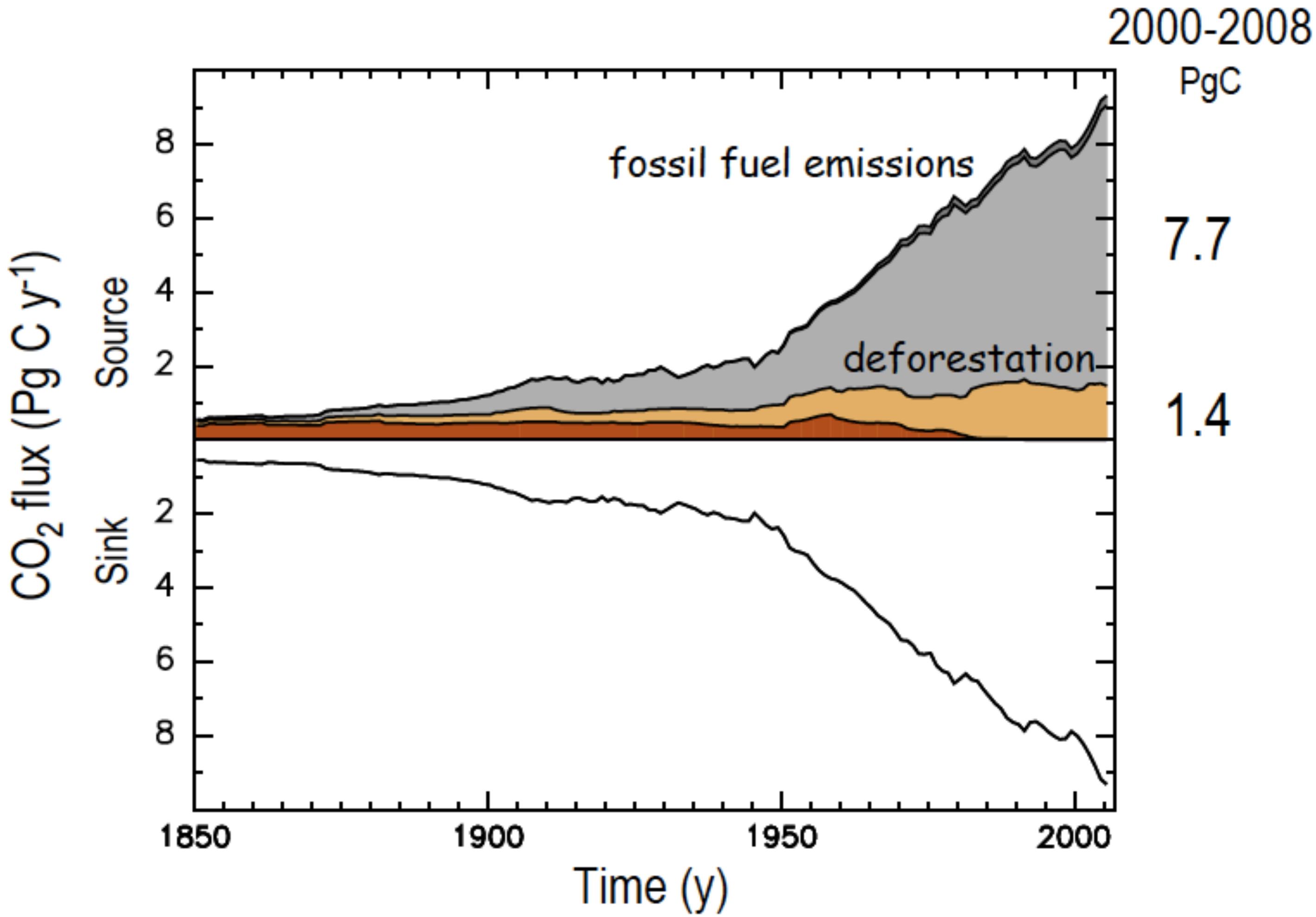
$^{14}CO_2$ observations : a proxy to infer fossil fuel emissions



Levin et al., pers com.

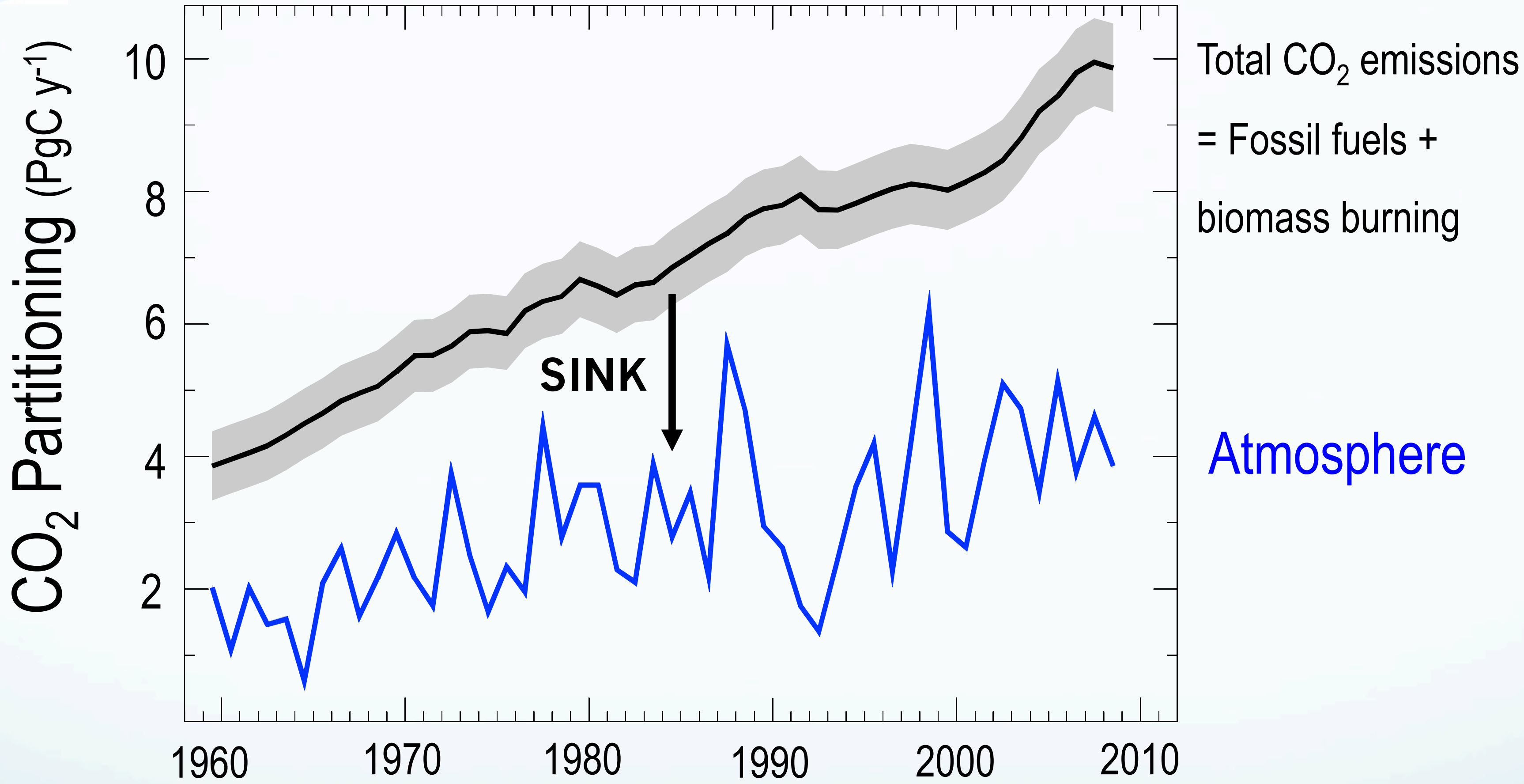
- *Present increase of CO_2 concentrations is due to anthropgenic emissions as proved by ^{14}C observations in polluted areas.*

Human Perturbation of the Global Carbon Budget



Global Carbon Project 2009; Le Quéré et al. 2009, Nature Geoscience

Natural CO_2 sinks : a 55% discount on climate change

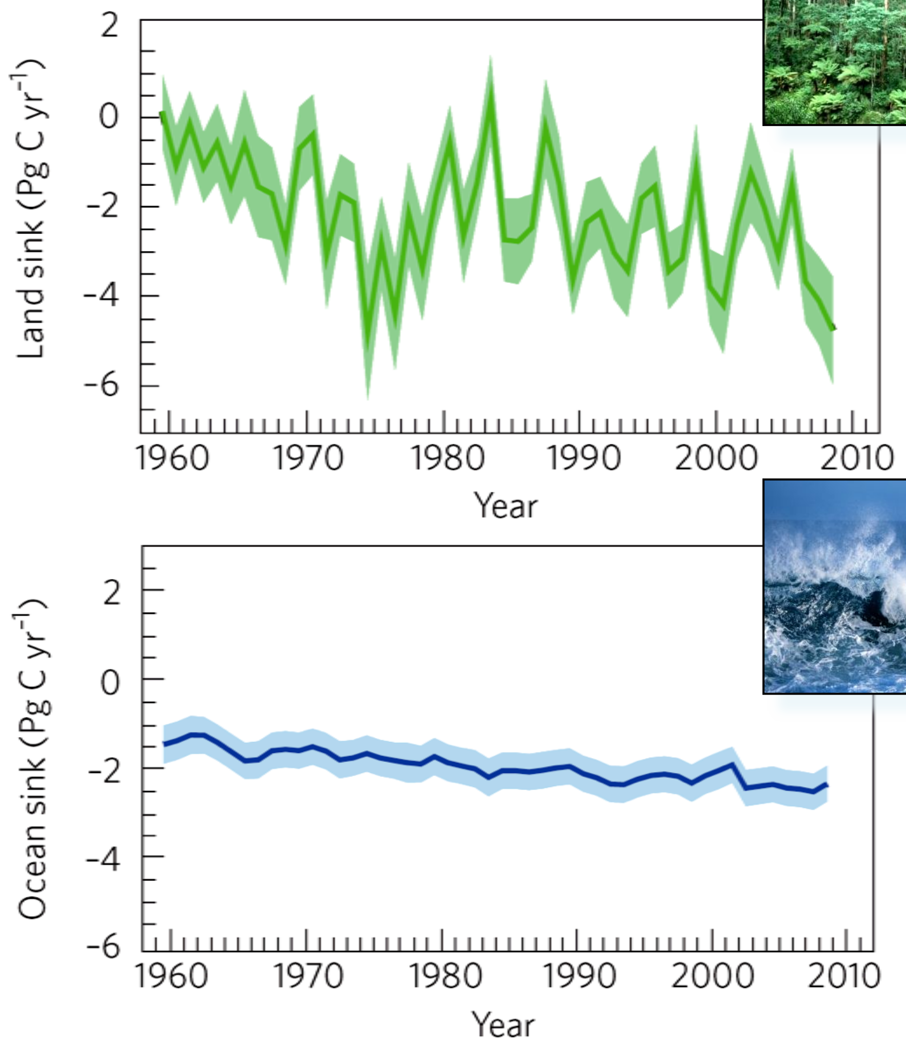


- Oceanic and land sinks correspond to the difference between emissions and atmospheric accumulation

- Only 45% of fossil fuel emissions accumulate in the atmosphere

Natural CO_2 sinks : land & ocean contributions

Modeled sinks



Factors:

Fertilisation effect
Nitrogen deposition
Climate variability
Forest regrowth
C residence time

Factors:

$pCO_{2,air}$-$pCO_{2,water}$
Marine biology
Ocean circulation
Nutrient limitation

Le Quéré et al. 2009, Nature-geoscience

Fate of Anthropogenic CO_2 Emissions (2000-2008)

1.4 PgC y^{-1}

+

7.7 PgC y^{-1}

Le Quéré et al. 2009, Nature-geoscience; Canadell et al. 2007, PNAS, updated

4.1 PgC y^{-1}

45%

3.0 PgC y^{-1}

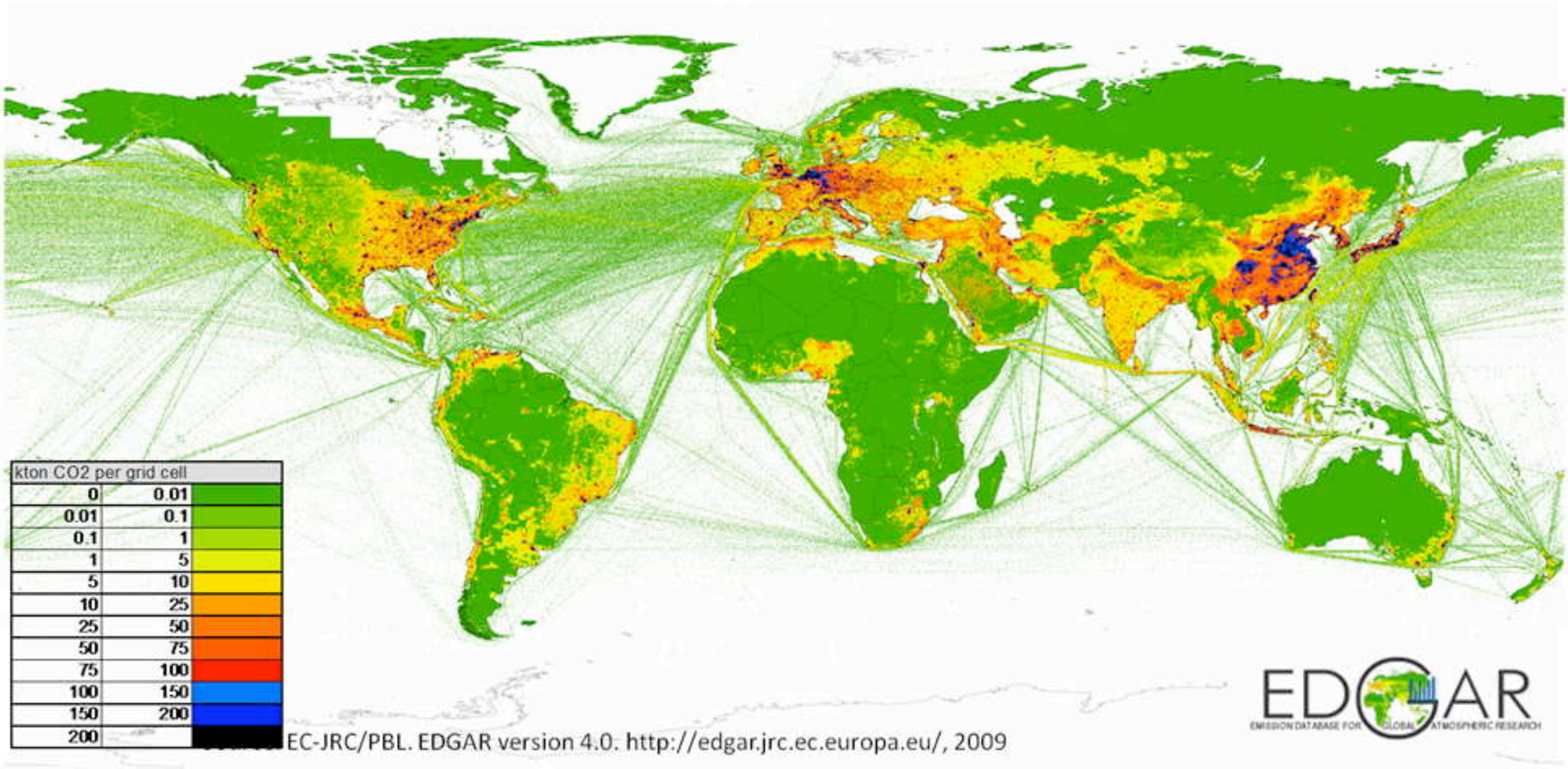
29%

26%

2.3 PgC y^{-1}

Long-term stability of the natural sinks ?

Annual map of surface CO_2 emissions due to fossil fuel use



- *Important role of developed countries*
- *Emerging countries are visible*

Cumulative Fraction of Total FF Emissions 2008

Number of Countries	Country	Cumulative Fraction
1	China	.232
2	USA	.419
3	India	.477
4	Russia	.530
5	Japan	.573
6	Germany	.599
7	Canada	.617
8	UK	.633
9	South Korea	.652
10	Iran	.668
20	Poland	.800
50 (2005)	Belarus	.941
100 (2005)	Moldova	.992
210		1.00

3 countries
50% Global Emissions

10 countries
2/3 Global Emissions

Top 5 + EU
80% Global Emissions

Gregg Marland, CDIAC 2009

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210		1.00

3 countries
50% Global Emissions

10 countries
2/3 Global Emissions

Top 5 + EU
80% Global Emissions

BUT

1 American

emits

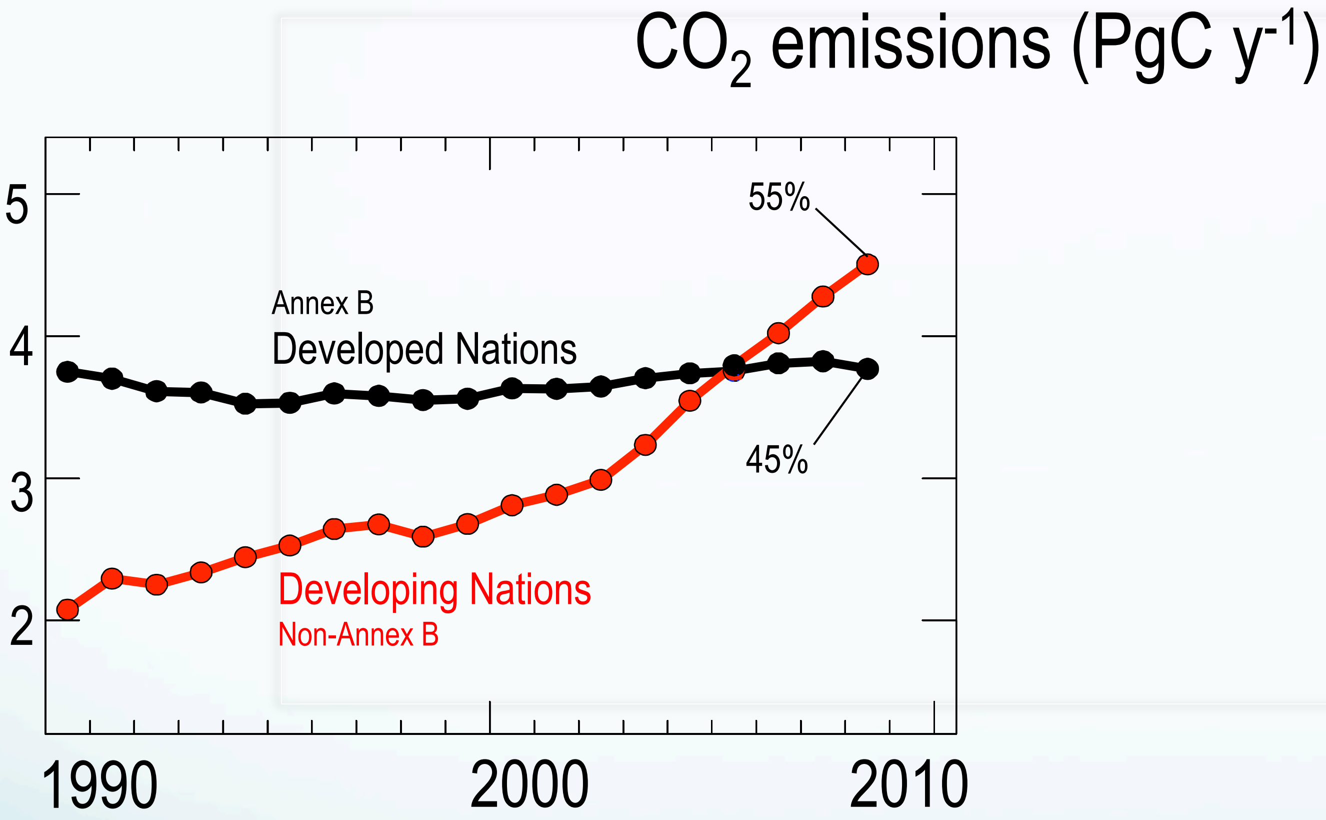
2 times more CO_2 than a European

and

5 times more CO_2 than a Chinese

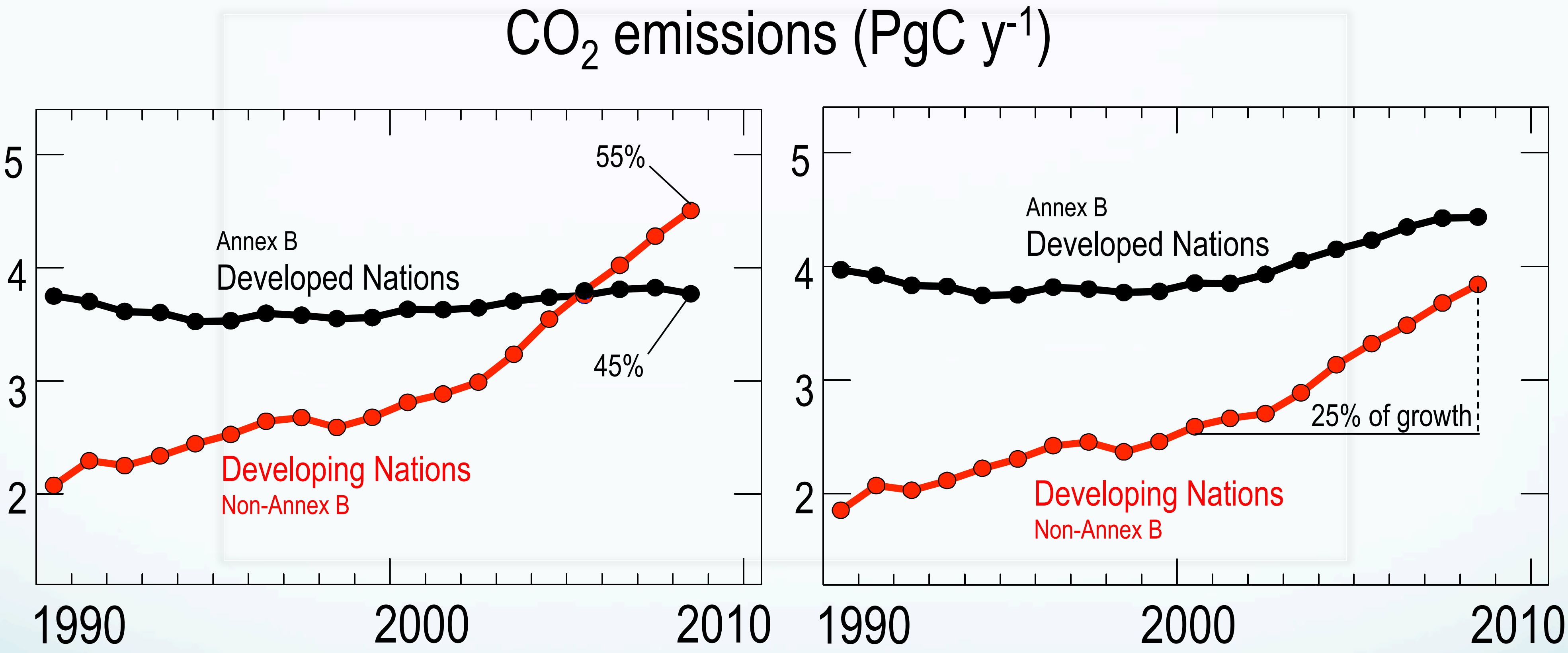
Gregg Marland, CDIAC 2009

Transport of Embodied Emissions



Global Carbon Project 2009; Le Quéré et al. 2009, Nature-geoscience; Data: Peters & Hetwich 2009; Peters et al. 2008; Weber et al 2008; Guan et al. 2008; CDIAC 2009

Transport of Embodied Emissions



Carbon associated to products build in China but used in developed countries should be attributed to the latter.

Global Carbon Project 2009; Le Quéré et al. 2009, Nature-geoscience; Data: Peters & Hetwich 2009; Peters et al. 2008; Weber et al 2008; Guan et al. 2008; CDIAC 2009

Drivers of Anthropogenic Emissions

- **KAYA equation**

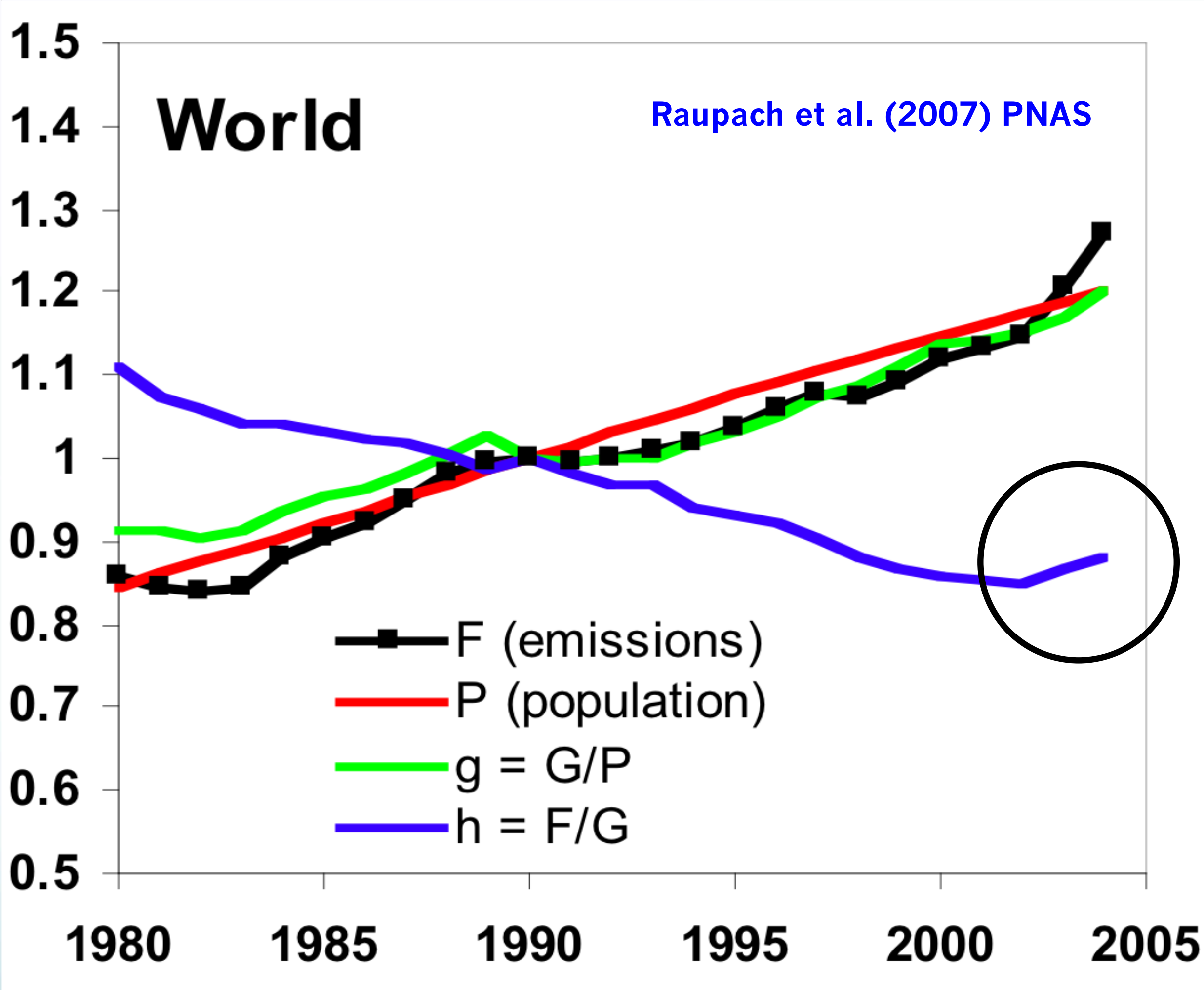
$$F = P \times \frac{G}{P} \times \frac{F}{G}$$

CO2 fossil emissions

Population

Gross Domestic Product

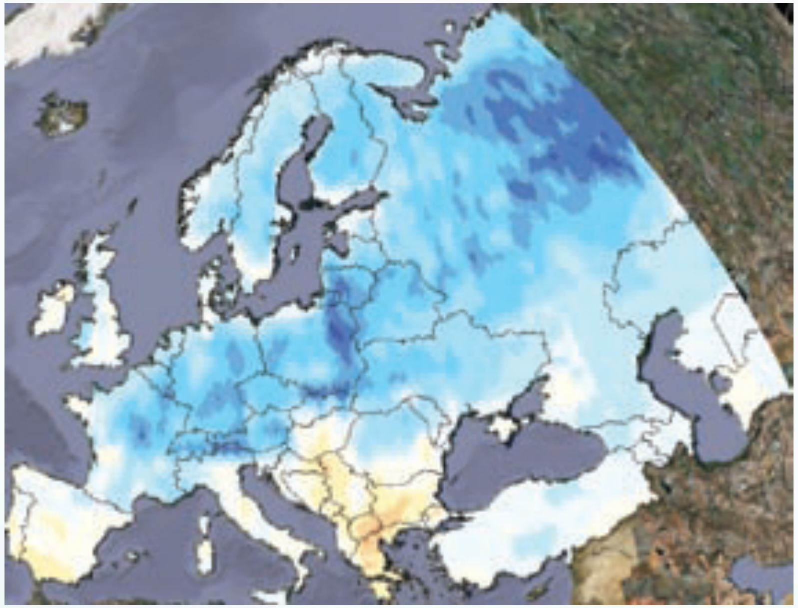
Carbon intensity

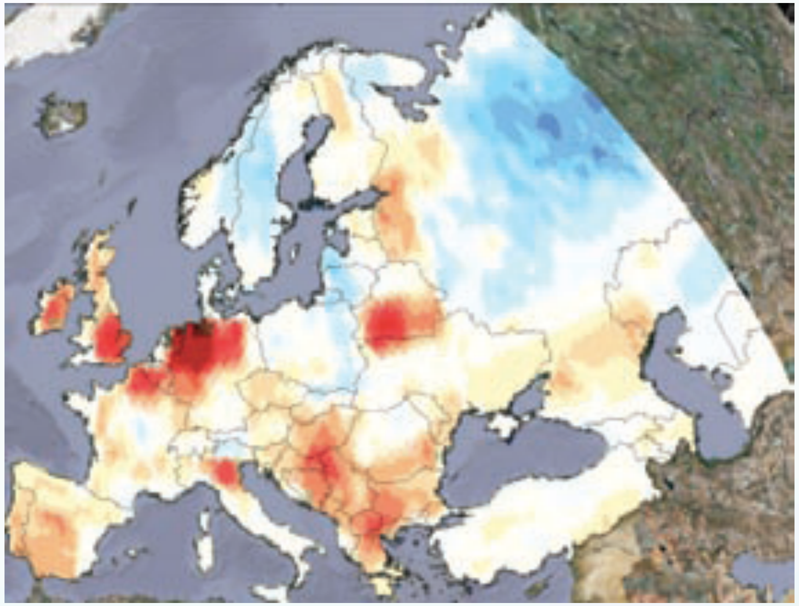


Divided by 2 means divided by 5 in fact ?

Accounting for all GHG do matter

CO_2 natural sink only	CO_2 natural sink + CH_4 & N_2O emissions





-0.27 ±0.16 GtC	-0.03±0.19 GtC

Accounting for all GHG changes continental Europe from a net sink to neutral

Schulze et al., Nature Geosciences, 2009

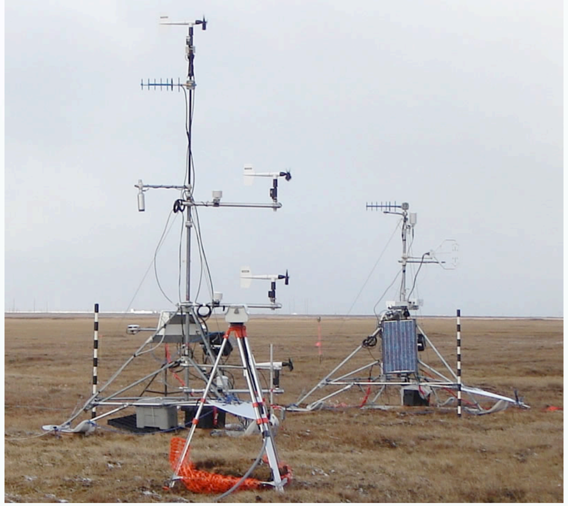
OUTLINE

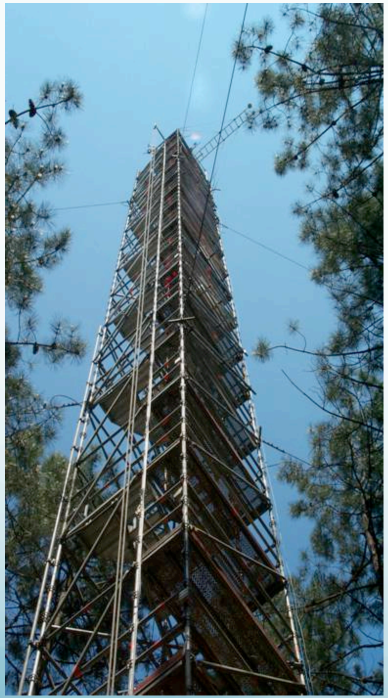
- Present carbon cycle
- **Inferring surface fluxes from atmospheric observations**
- Scales and constraints

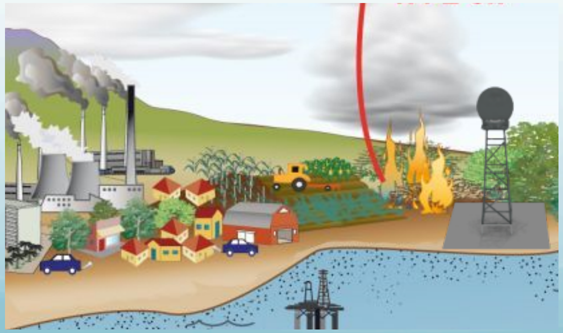
Direct measurements of GHG fluxes

- Flux towers with eddy correlation measurements (CO_2). Typical fetch 1 km^2

- Flux chambers (CH_4, N_2O)







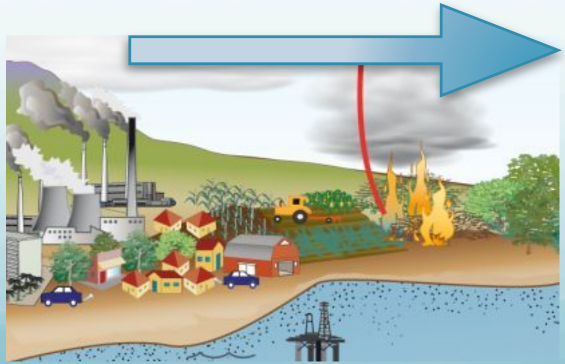
Local scale

Inferring surface fluxes only with observations: Radon method

- Downwind simultaneous measurements of a gas and of Radon-222 (natural radioactive gas)

- Assuming colocation of sources and a perfect knowledge of Rn222 emissions allows to derive the unknown gas flux :

- $F_{gas} \approx F_{Rn222} \frac{C_{gas}}{C_{Rn222}}$

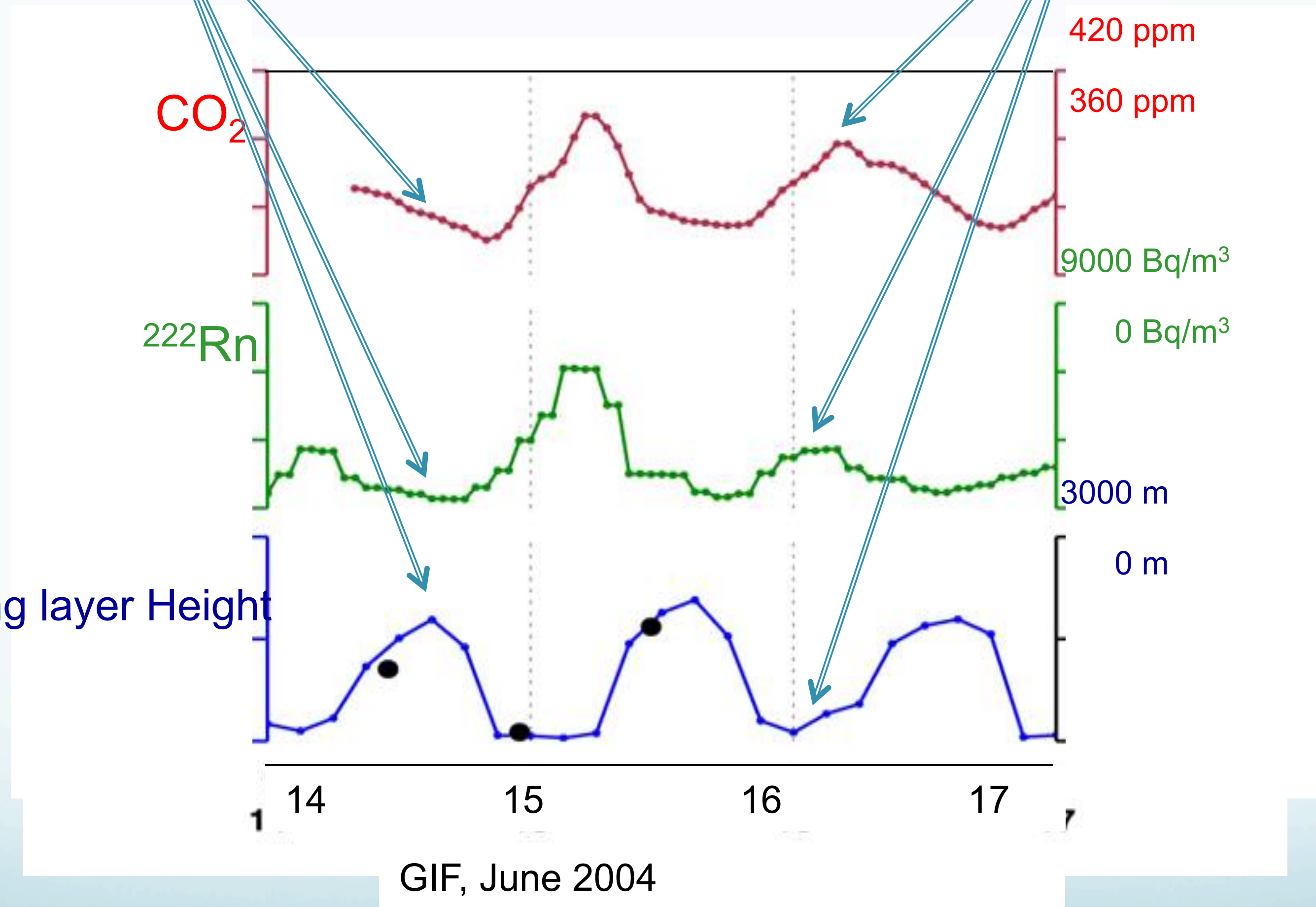


Local to regional scales

Illustration at Saclay

Low CO2 lowRn,
High ML height

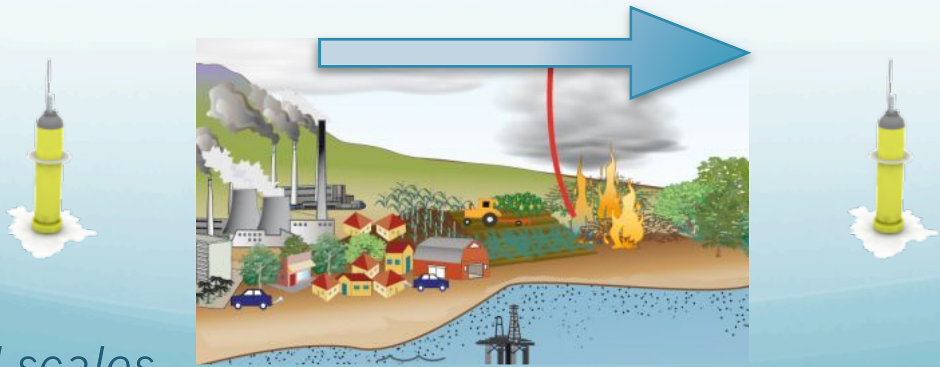
High CO2 High Rn,
low ML height



Correlation between trace gases can help understanding the carbon cycle

Inferring surface fluxes only with observations: 2 sites

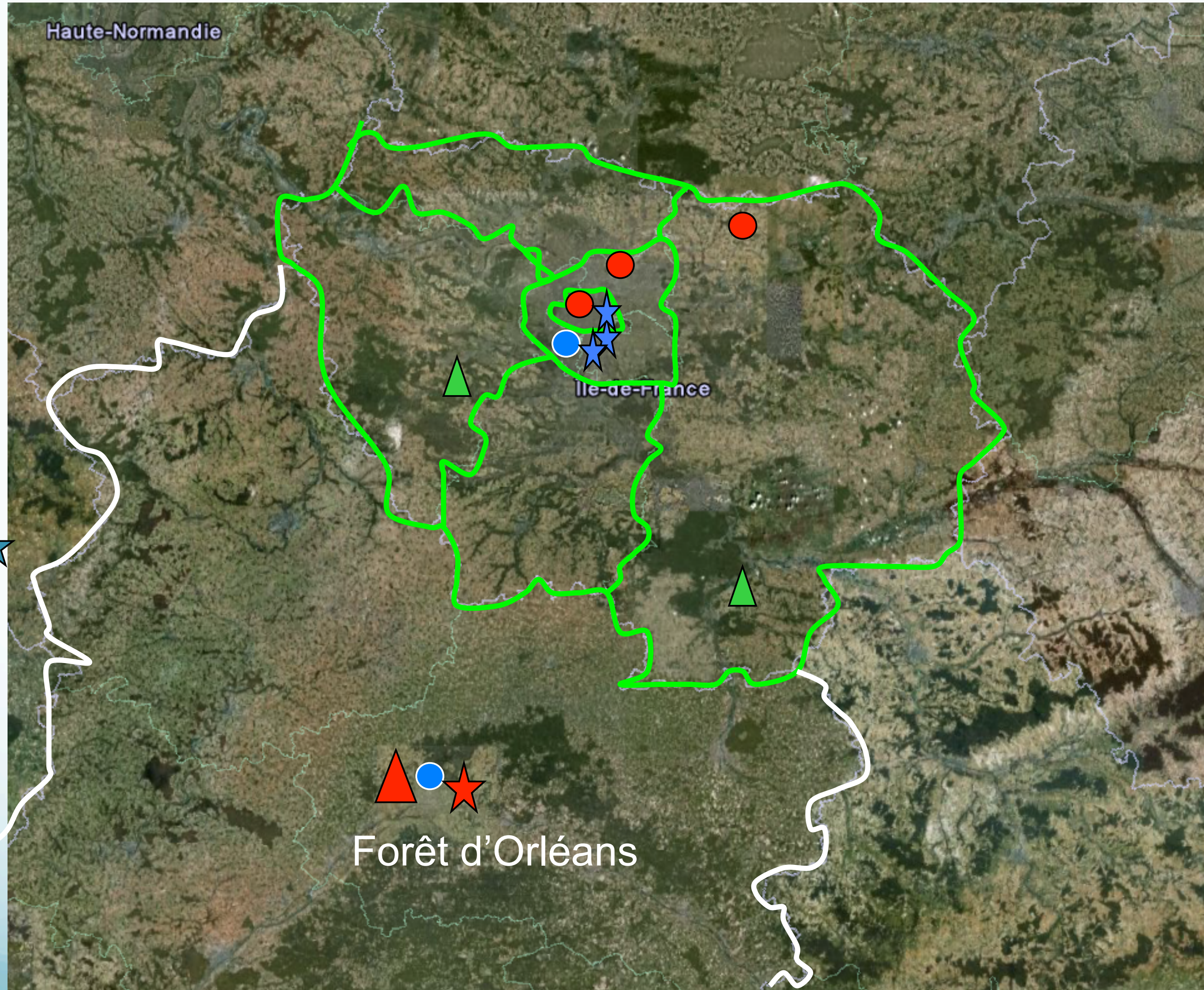
- Upwind & Downwind measurements of a GHG
- Assuming or measuring the mixing layer height (*h*) allows to derive the unknown gas flux :
- $F_{gas} \approx \Delta C_{gas} h$

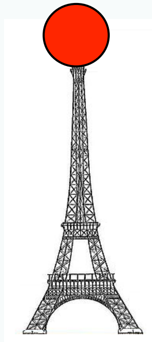


An atmospheric network to constrain GHG emissions from Paris

Upwind and downwind stations

CO_2
-CO
-^{14}C of CO_2
-Bio flux
-ML height

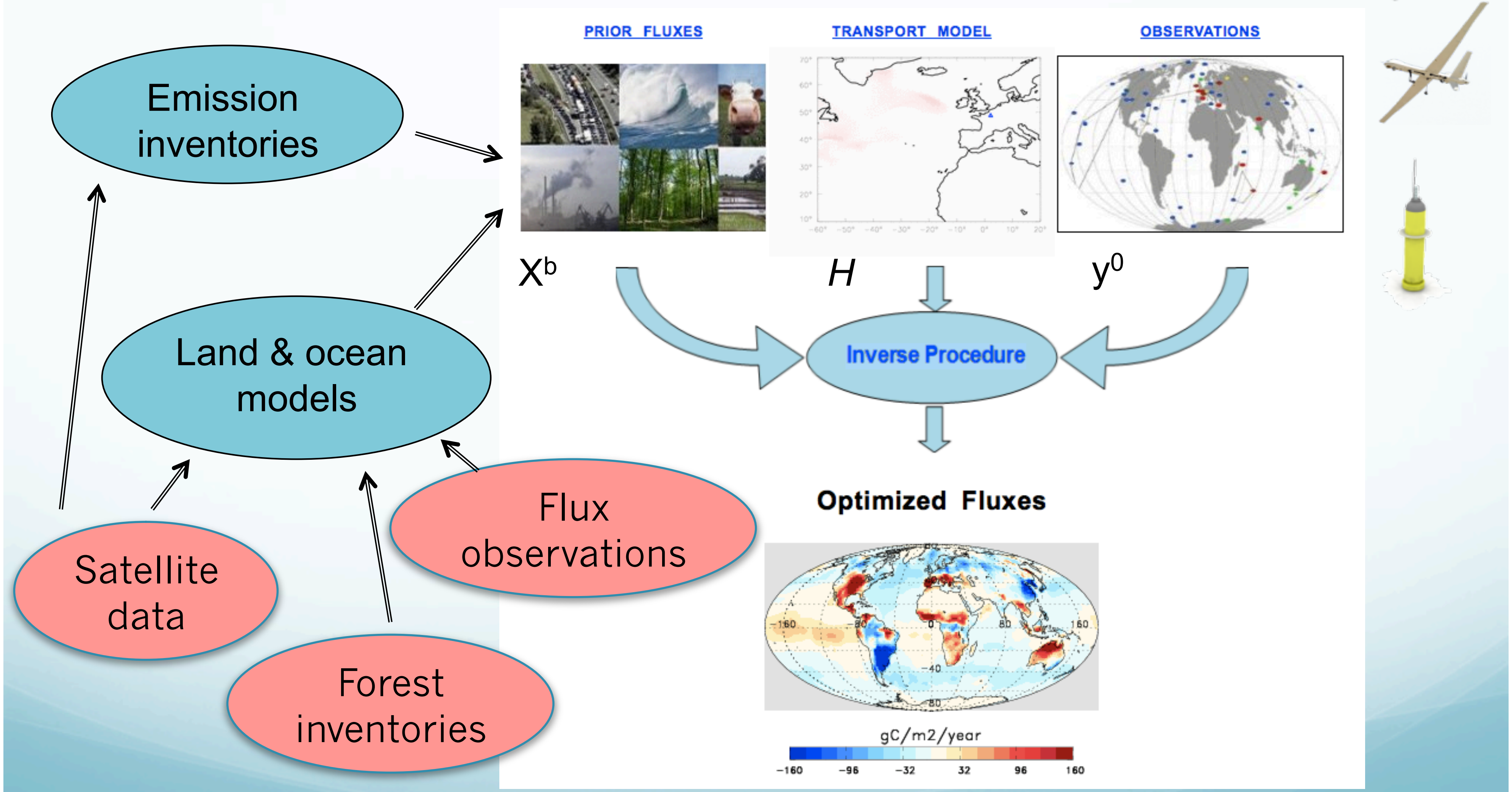




Xueref, pers. Comm.

Inferring surface fluxes using inverse modelling

$$J(\mathbf{x}) = \frac{1}{2}\left(\mathbf{y}^0 - H(\mathbf{x})\right)^T \mathbf{R}^{-1}\left(\mathbf{y}^0 - H(\mathbf{x})\right) + \frac{1}{2}\left(\mathbf{x} - \mathbf{x}^b\right)^T \mathbf{B}^{-1}\left(\mathbf{x} - \mathbf{x}^b\right)$$

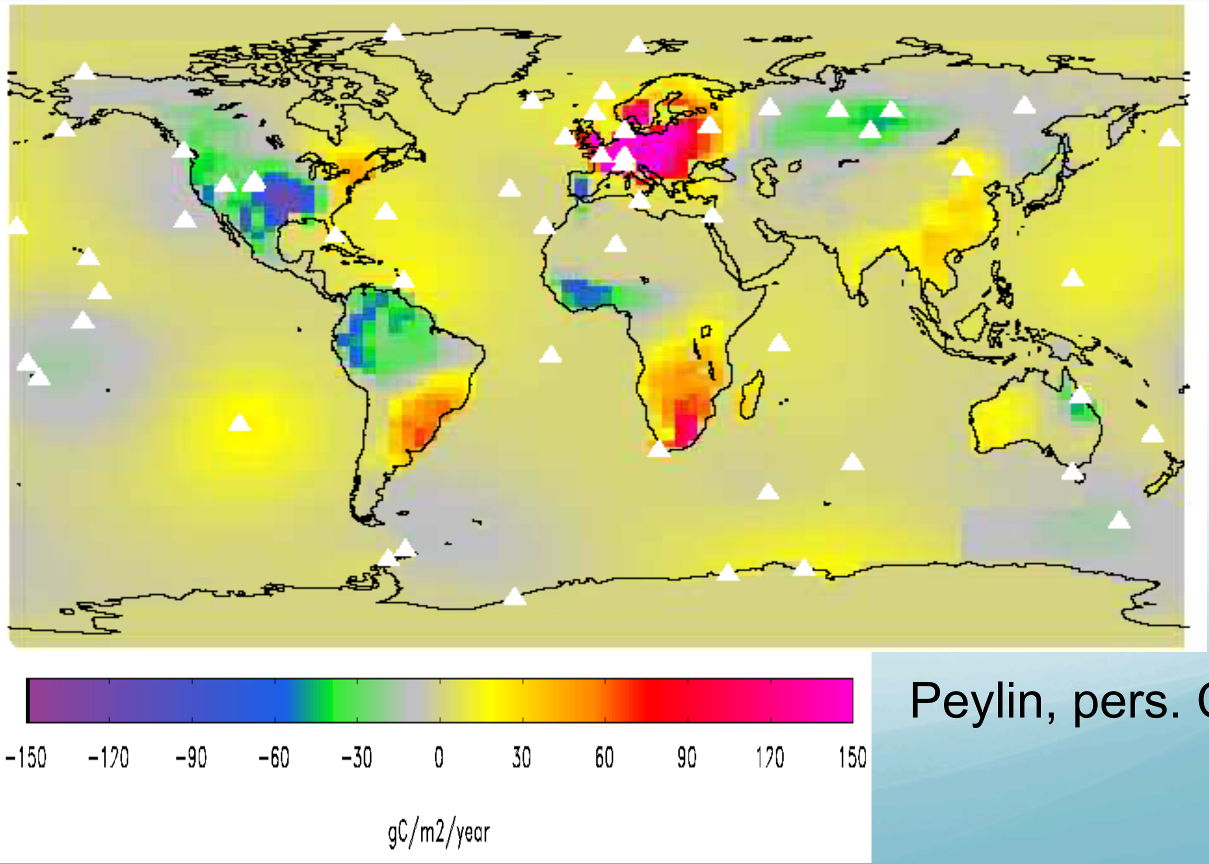


All scales (depending on resolutions of model, prior & observations)

Global inversion

- Low resolution model 3.75°x2,5° (LMDZ model)
- Analysed meteorology (ECMWF)
- Land surface CO2 fluxes: ORCHIDEE
- anthropogenic fluxes: EDGAR inventory
- 1 year of atmospheric inversion (analytical method)

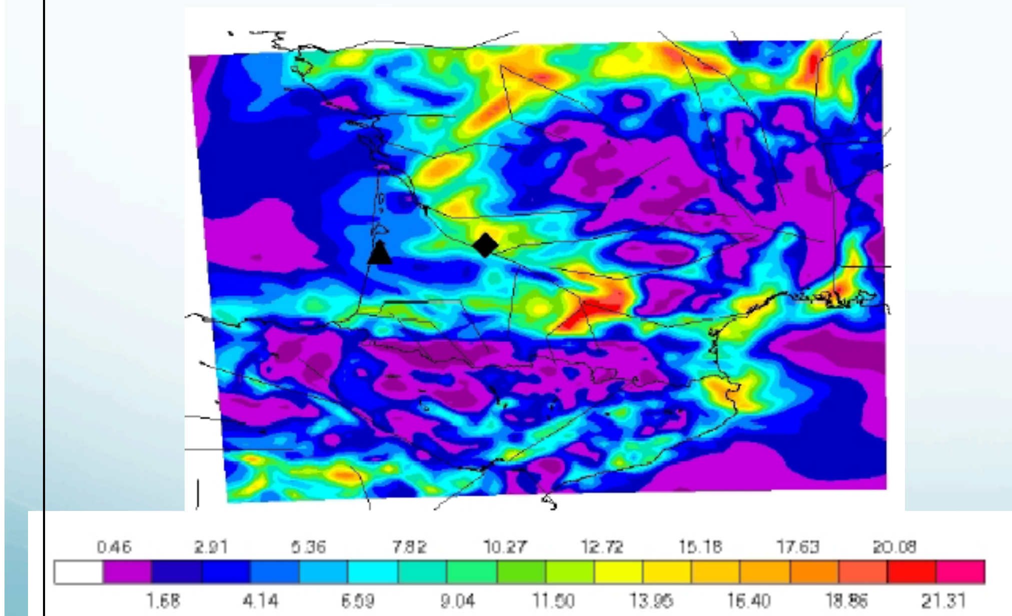
CO_2 flux anomaly
for summer 2003
(heat wave in Europe)



Peylin, pers. Comm.

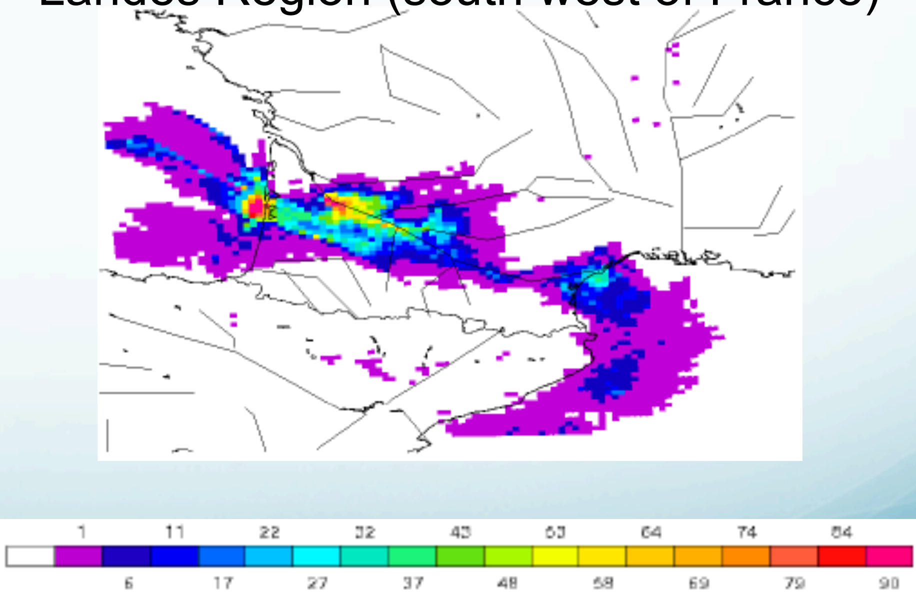
Regional inversion

- High resolution model 2,5x2,5 km^2 (AROME ou Meso-NH + LPDM)
- Urban meteorology(TEB: V. Masson, CNRM/GAME)
- Land surface CO2 fluxes: ORCHIDEE-STICS, CERES-EGS
- anthropogenic fluxes: CITEPA HR
- 1 year of atmospheric inversion (vatiational assimilation)
- Estimation of CO2 fluxes and of the error reduction due to observations



CO2 variability in May 2005
Lauvaux et al., 2009

Landes Region (south west of France)



Error reduction due to observation assimilation
Lauvaux et al., 2007

OUTLINE

- Present carbon cycle
- Inferring surface fluxes from atmospheric observations
- **Scales and constraints**

IPCC Recommandations, 2007 report

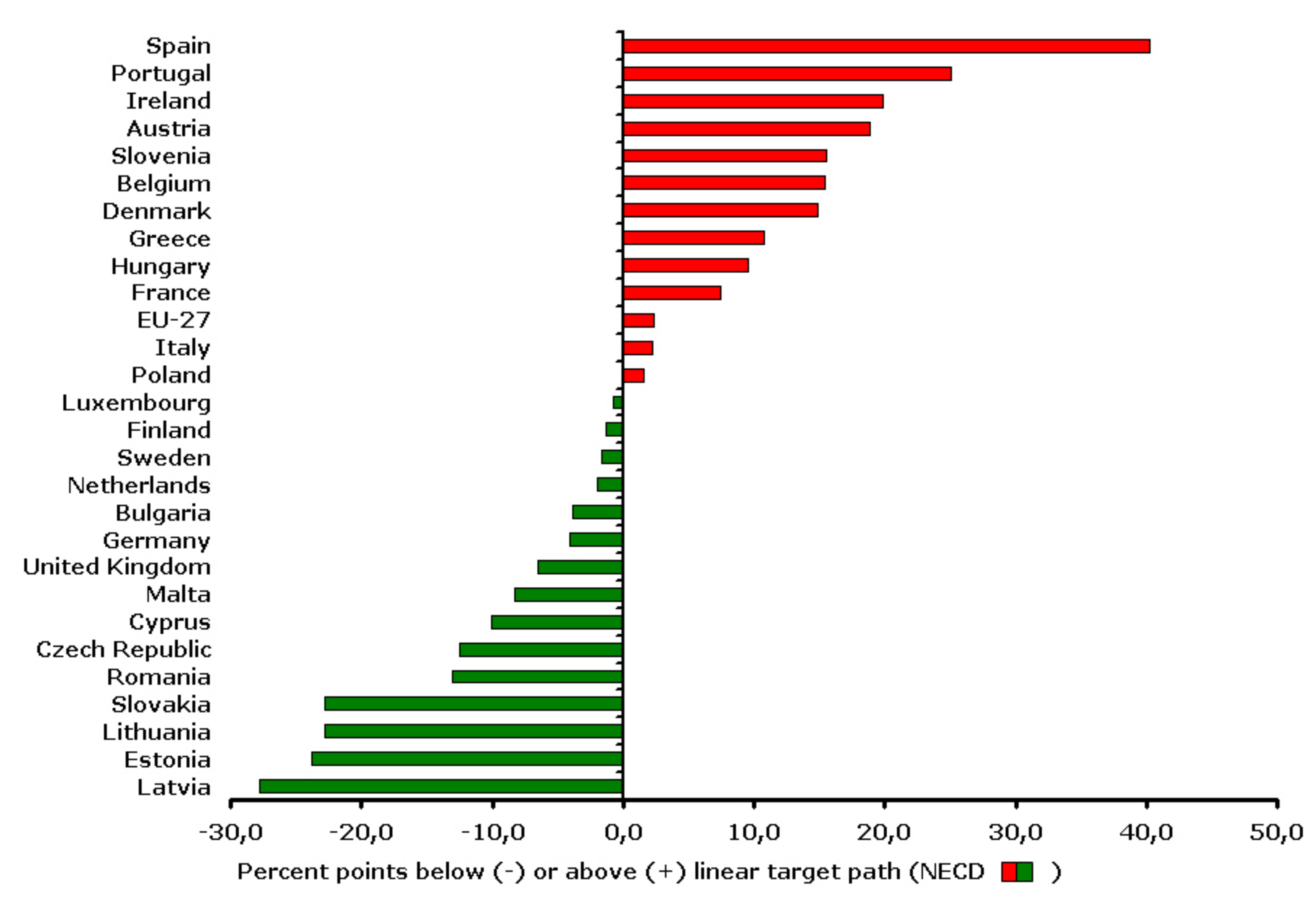
• Limit Temperature increase to +2 deg to avoid irreversible damages
• Implies a 25 to 40% reduction in GHG for industrial countries by 2020
• World emissions will have to be divided by 2 by 2050 (while world popultaion will have increased by a factor 2)
• Implies a reduction of 85% by industrial countries by 2050 to allow for poor countries development

EU Objective of 3x20 by 2020

• -20% emissions (-30 if post Kyoto agreement)
• 20% increase in energy efficiency
• 20% renewable energy

Kyoto Protocol

- -8% in GHG emissions in Europe 15, over period 1990-2012. For France, stability of emissions.



Climat Plans:
Brief history in France

- 2000 National Program against climatic change (PNLCC).

- 2003 Factor 4 between 1990 and 2050; law past in july 2005 under the form 3% reduction per year

- 2004 French Climate Plan: Scenarios for 2050. Transport, Buildings, Industry, Agriculture, Air conditioning, Plans climats territoriaux

- Nov 2006 Second climat plan. Respecting Kyoto, level of 1990 for Fr. Carbon tax, labelling, alternative mobility, biofuels, energy efficient buildings.

- 2007 Grenelle de l'environnement more ambitious objectives. Scenarios for 2020 compatible with 3x20 and factor 4.

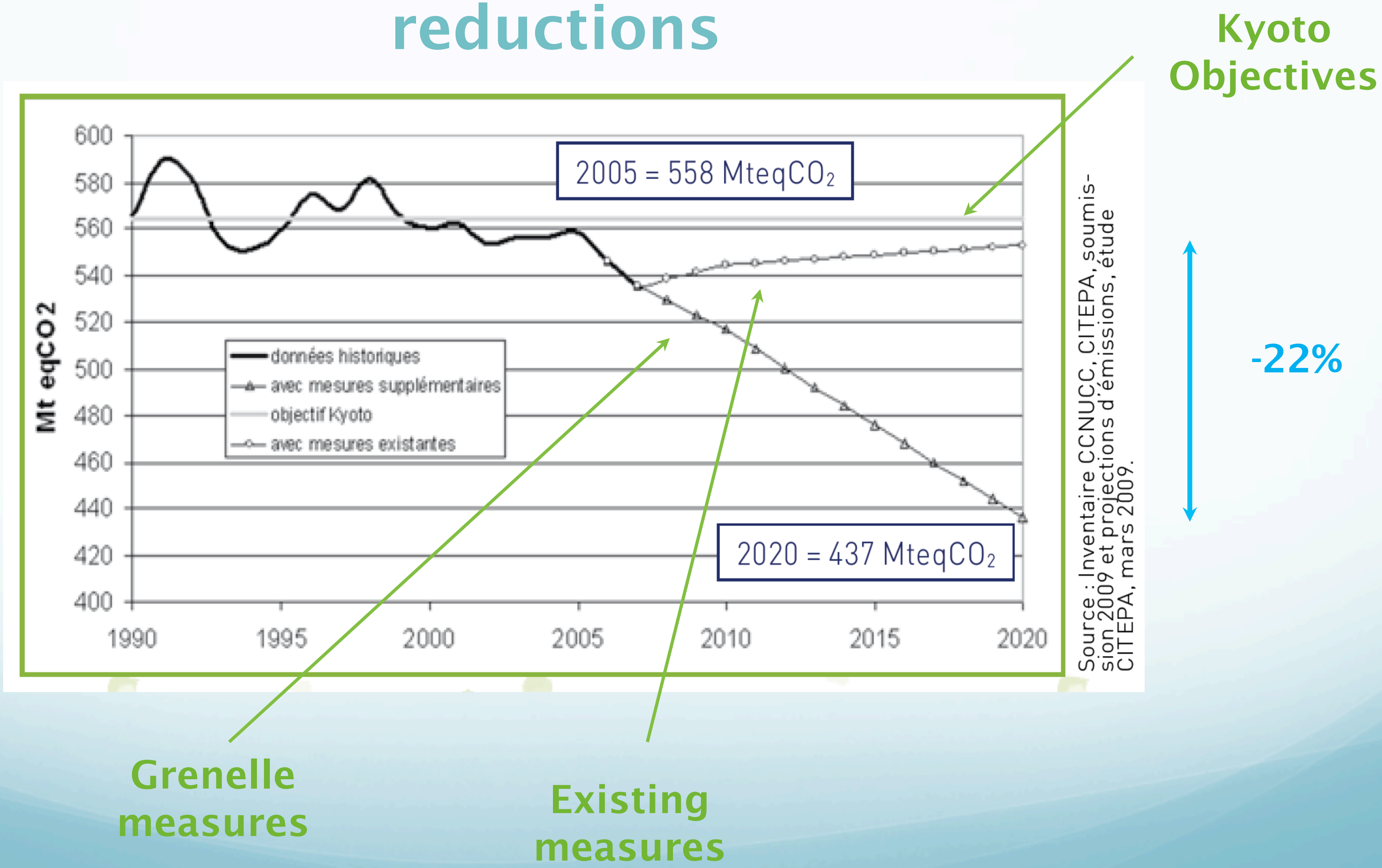
- Dec 2008 « Paquet Energie Climat » -14% between 2005 and 2020 for emissions not covered by quotas

- Dec 2009 first Climat Plan at territorial level signed (North of France)

Climat Plans Objectives

MteqCO2	1990	2005	2020	Delta 1990-2020	Delta 2005-2020	Comments
France: National Climat Plan	565	558	437	-22,8%	-21,8%	Grenelle Fr: -14% no quota emissiosn (Paquet); -21% on quota emissions (UE objectif)
Fr: Sectors not submited to quotas (housing, transport, …)		408	333		-18,3%	EU objectif -10,5%
Fr: Industry under quota emissions		150	104		-31,4%	EU Objective -21%
« Paquet Energie Climat »					-14%	Voted Dec 2008
EU	5564	5144	4451	-20%	-13,5%	

Climat Plan in France: Projection in GHG reductions



French Climat Plan
Per sectors

	MteqCO2 Delta 2020-2005	% 2020-2005	Means
Residential	55 MteqCO2	- 56%	Low energy or positive building Renovation
Industry	47 MteqCO2	- 31%	EU quota
Energy	31 MteqCO2	- 42%	Renewable energy Increased efficiency Coal factory closed
Transport	15 MteqCO2	- 11%	Alternative transport Vehicle emisssions

Territorial Plans in France

- Climat and energy territorial plans mandatory under Grenelle law (art 26-2) for regions over 50 000 inhabitants; to be adopted before end 2012
- Regional schemes for climat and energy to insure strategic national coherence
- Ex Thur Doller region in Alsace, 486 Km2, 65 000 inhabitants, 48 townships. 11 to 15 KtCO2/year in phase with factor 4 strategy; 3 year project (energy efficiency, quality of life, imporved habitat, economic det: eco-construction.

State of emissions in 2003: 620 KtCO2 (37% industry, 31% transport, 25% residential)
Efforts by citizens, industrials, local authorities

Take-home messages

- Carbon cycle is a key component of the earth system, with challenging uncertainties and feedbacks (e.g. climate-carbon feedback)

- Natural CO_2 sinks have provided a 55% discount on climate change.
For how long?

- All GHG are important to consider: H_2O (feedbacks), CO_2, CH_4, O_3, CFCs.

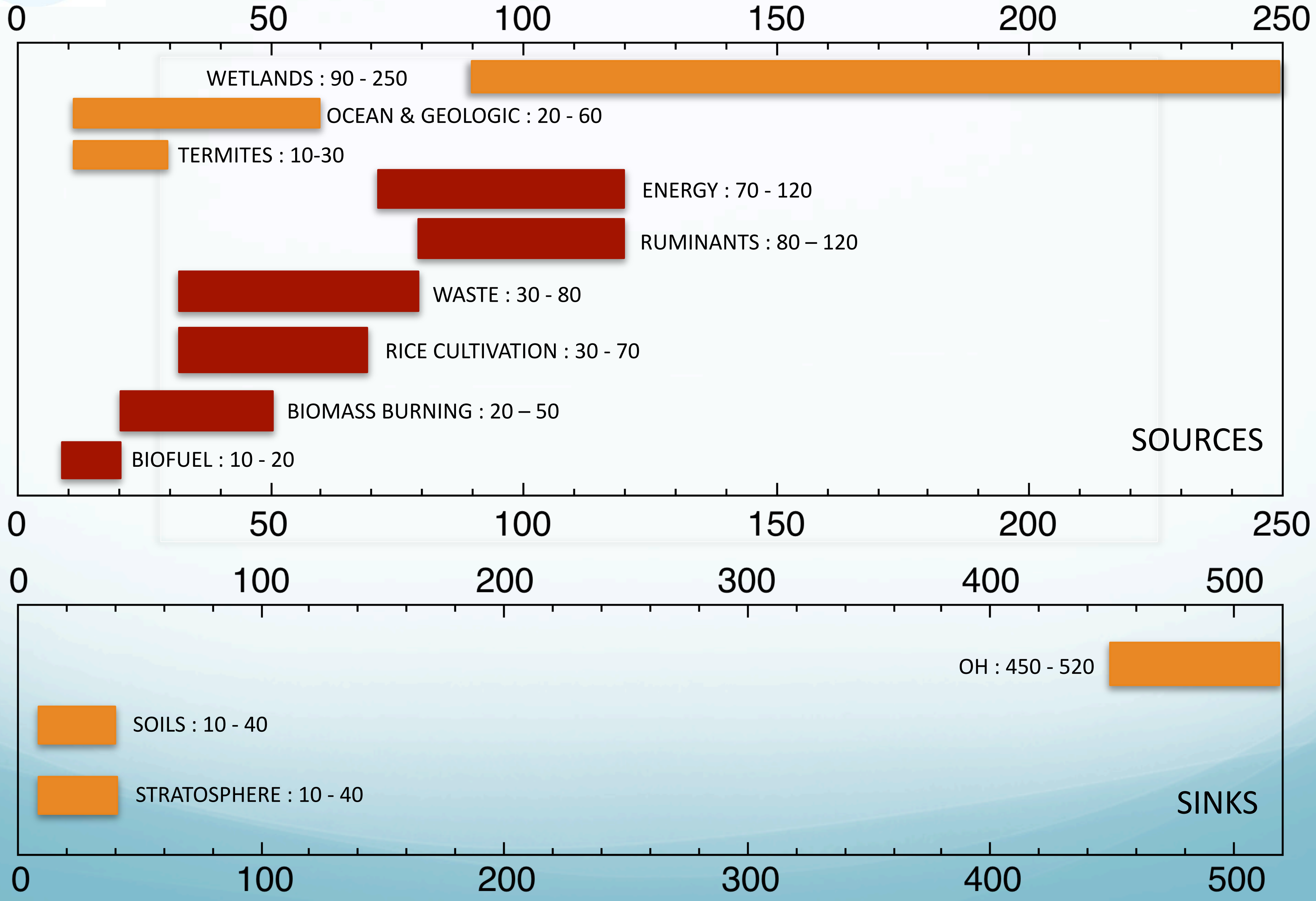
- Atmospheric observations of GHG can help estimating and verifying carbon emissions at various scales, from regional to global.

- The link between scientific results and potential end-users is to be built through the creation of new carbon products, e. g.: high resolution flux maps, integrated systems for regional flux estimates & verification, ecological carbon indicators, tools to attibute emissions to natural or anthropogenic sources, …

- International, national, and regional reglementation will put increasing constraints on the reliability of carbon products, stressing the importance to define them precisely in the next years

- This challenge is yours !

A bit of methane also …



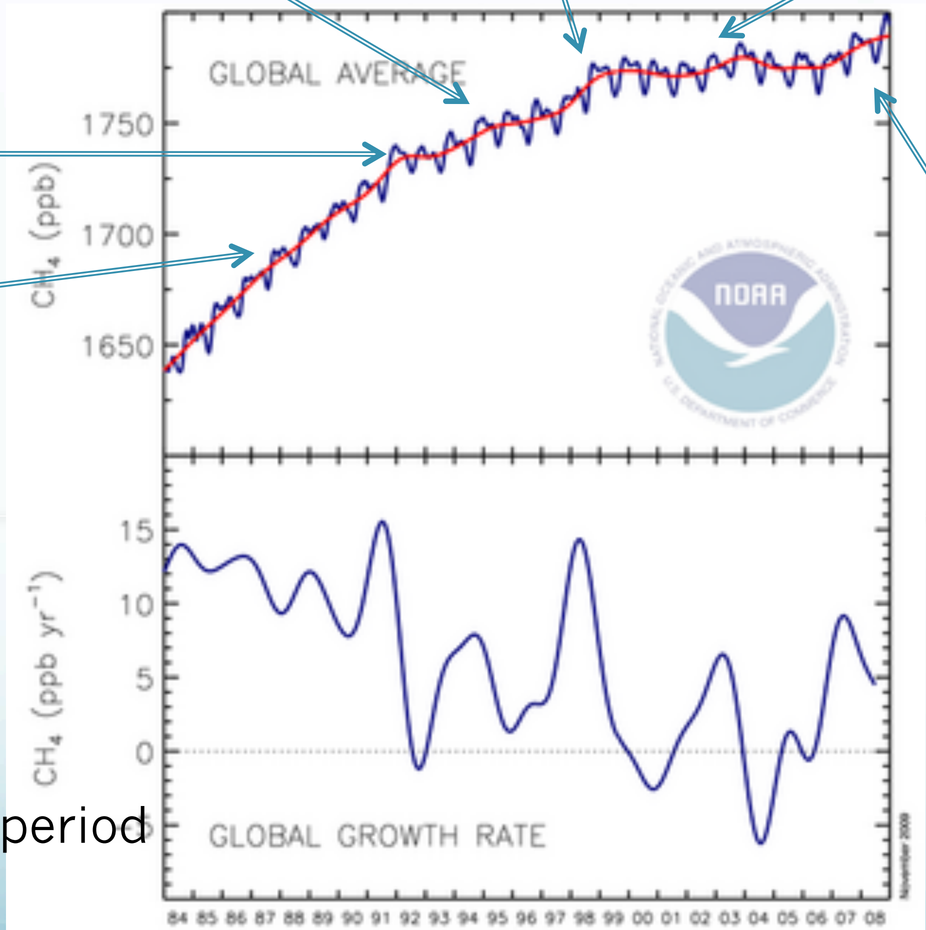
Evolution of atmospheric methane (surface)

Low growth rate period
1991-1996

El Niño
1997-1998

Stabilisation period
1999-2006

Pinatubo,
USSR collapse
1991-

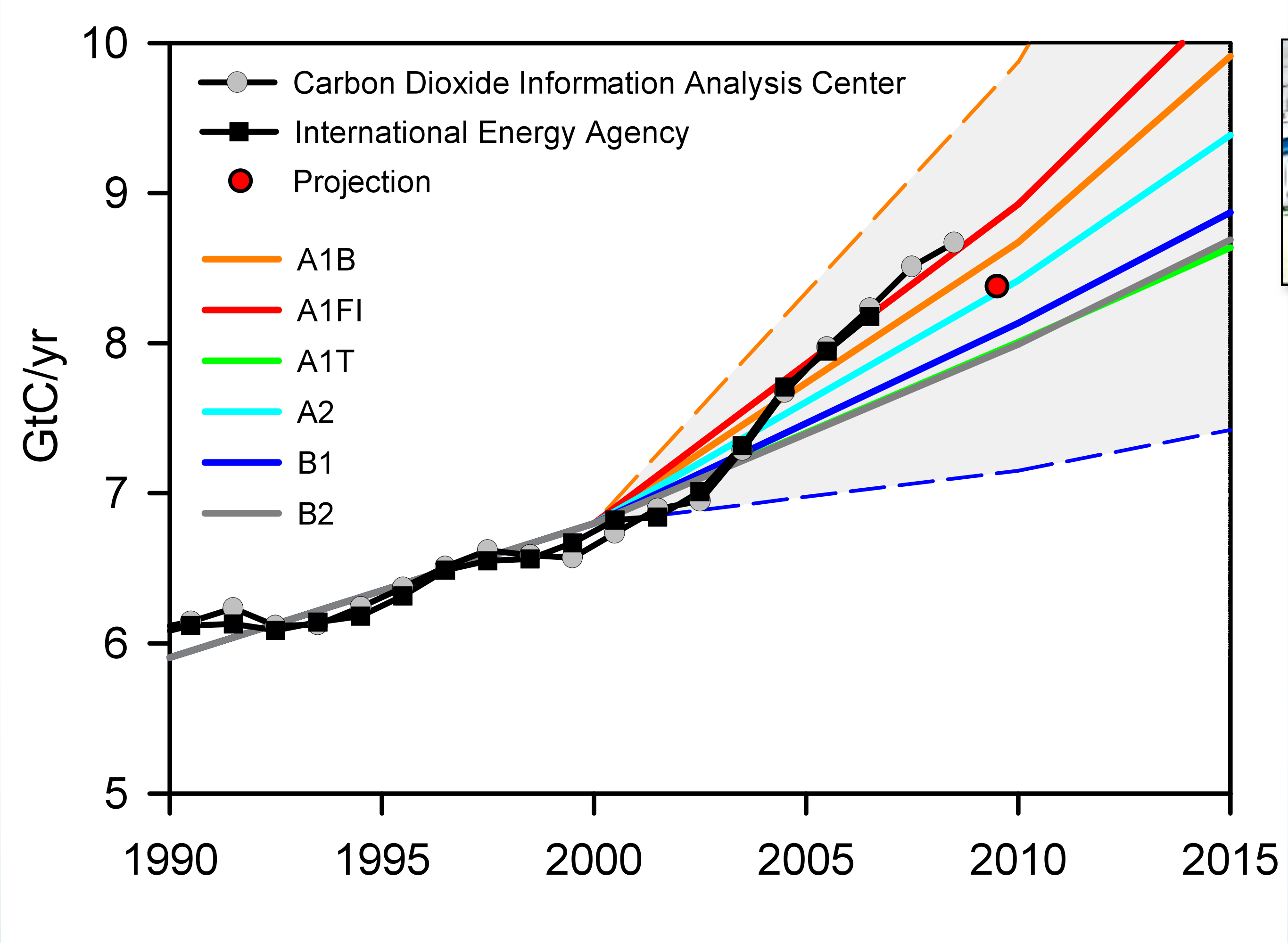


Recent increase
2007-

High growth rate period
< 1991

NOAA, ESRL

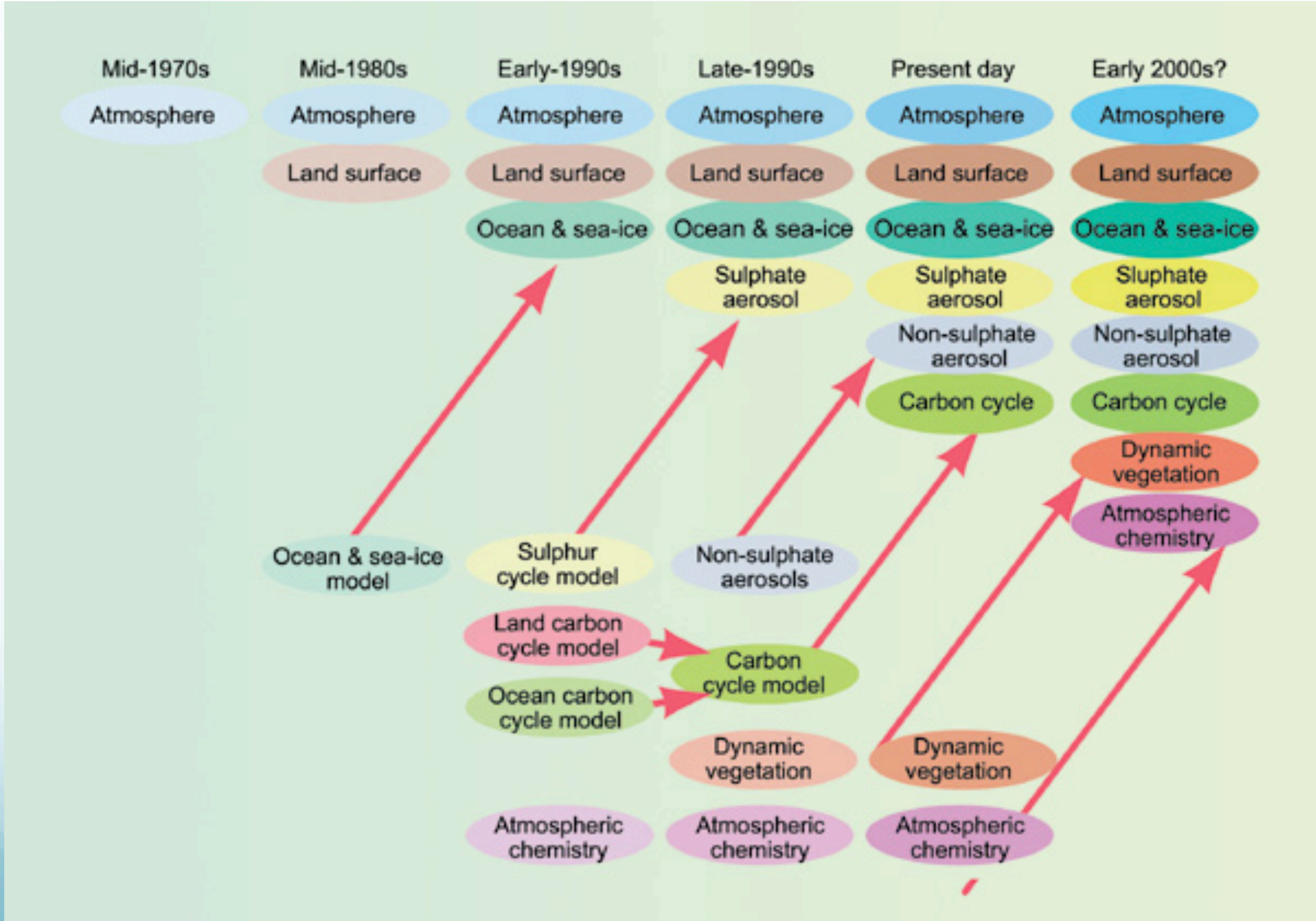
Fossil Fuel Emissions: Actual vs. IPCC Scenarios



Projection **2009**
Emissions: -2.8%
GDP: -1.1%
C intensity: -1.7%

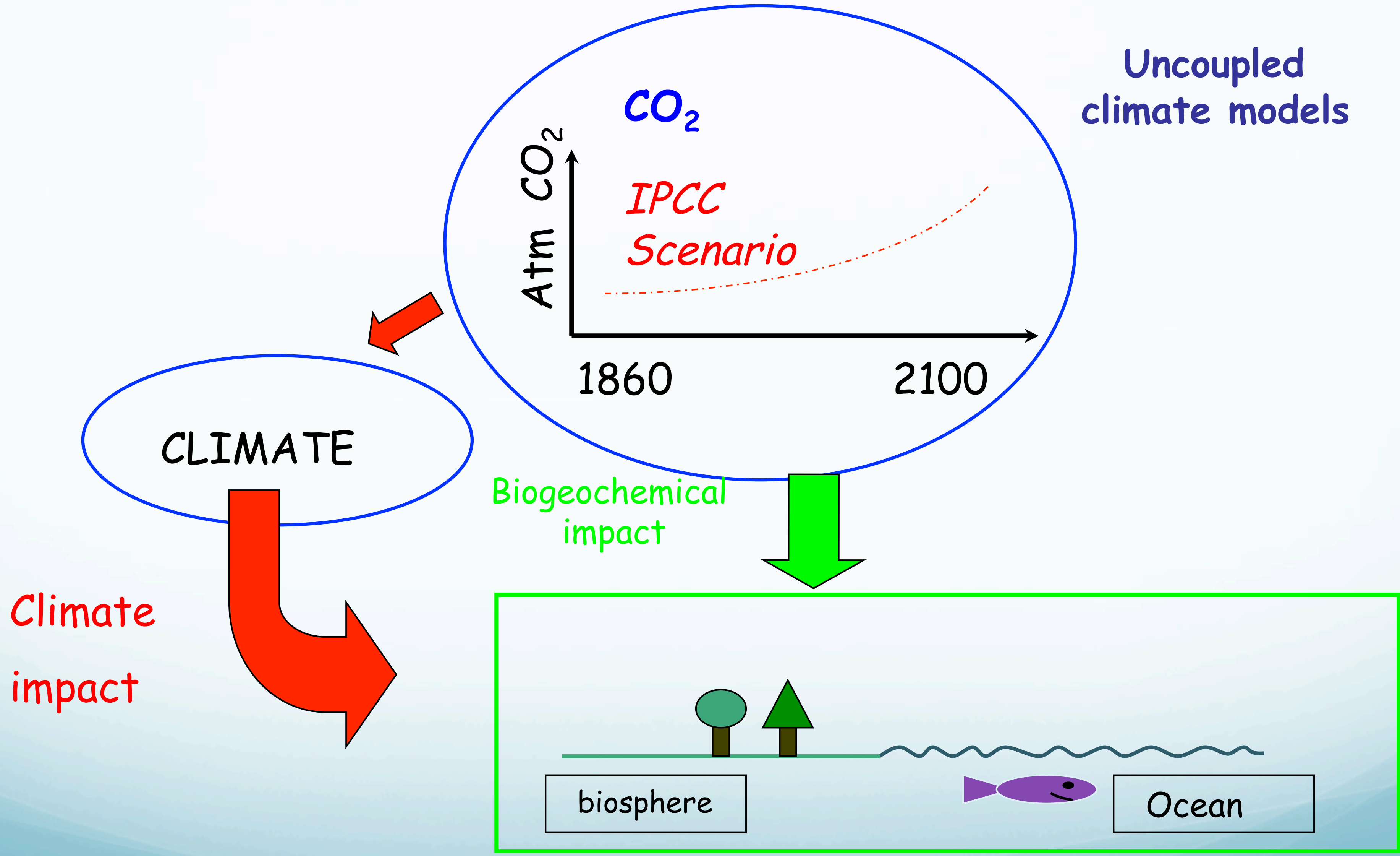
Raupach et al. 2007, PNAS, updated; Le Quéré et al. 2009, Nature-geoscience; International Monetary Fund 2009

Climate model evolution

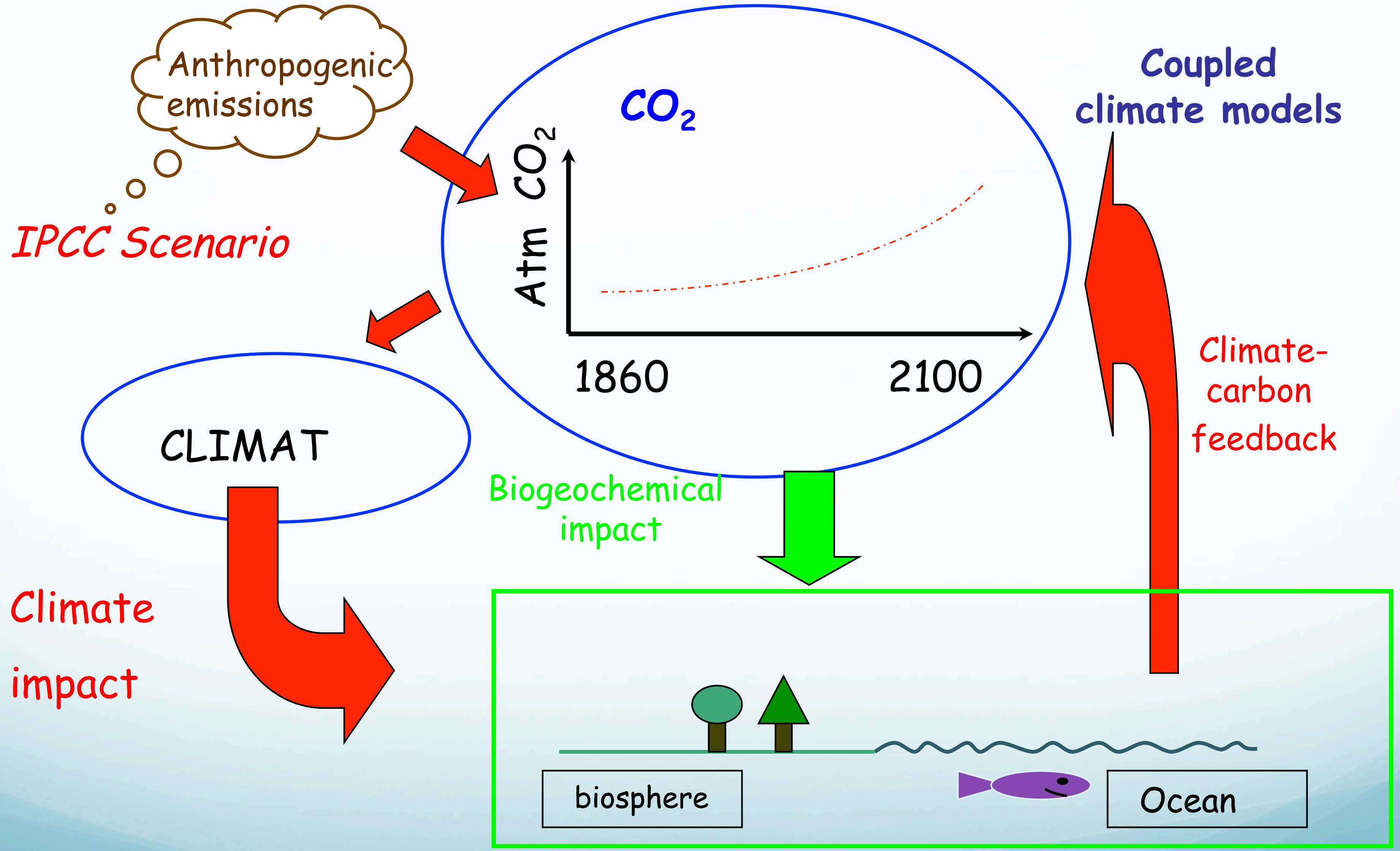


Source : IPCC

Climate-carbon feedback : OFF



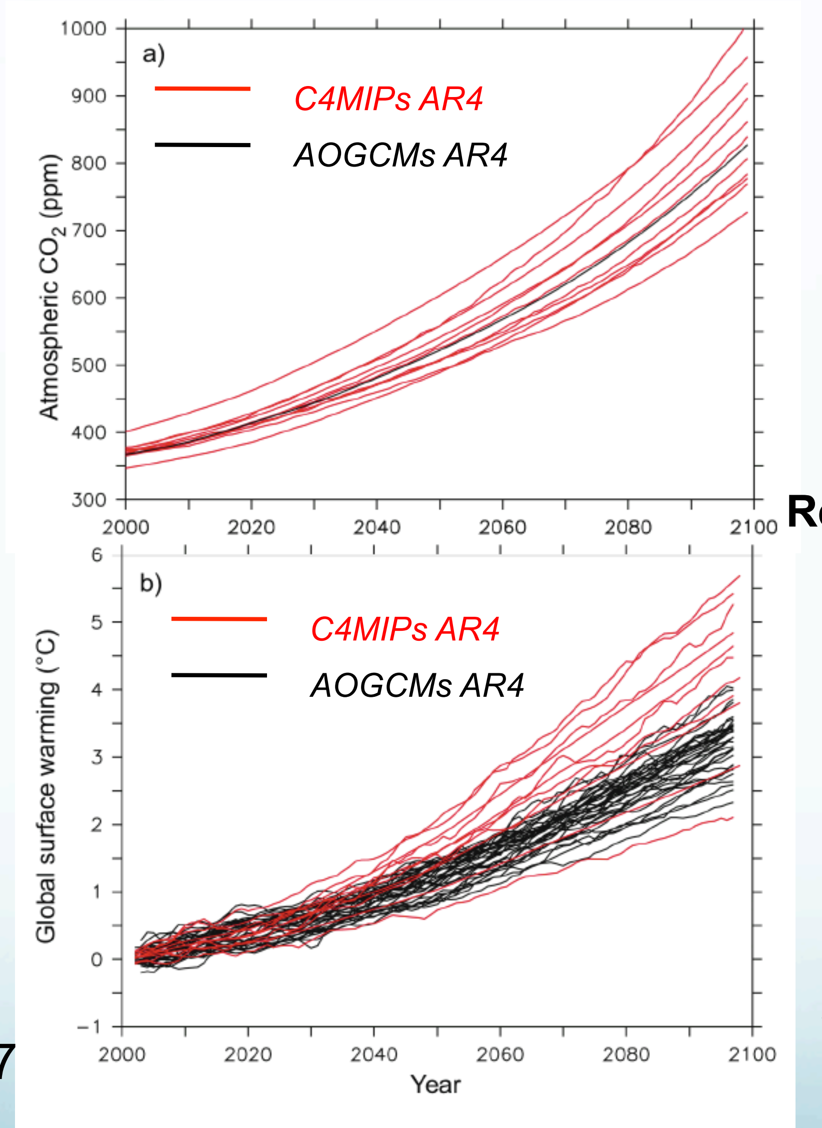
Climate-carbon feedback : ON



Results : atmospheric CO_2 increase and temperature

CO_2

Température



IPCC, 2007

830 ppm

700 – 1000 ppm

Regular climate AR4 models

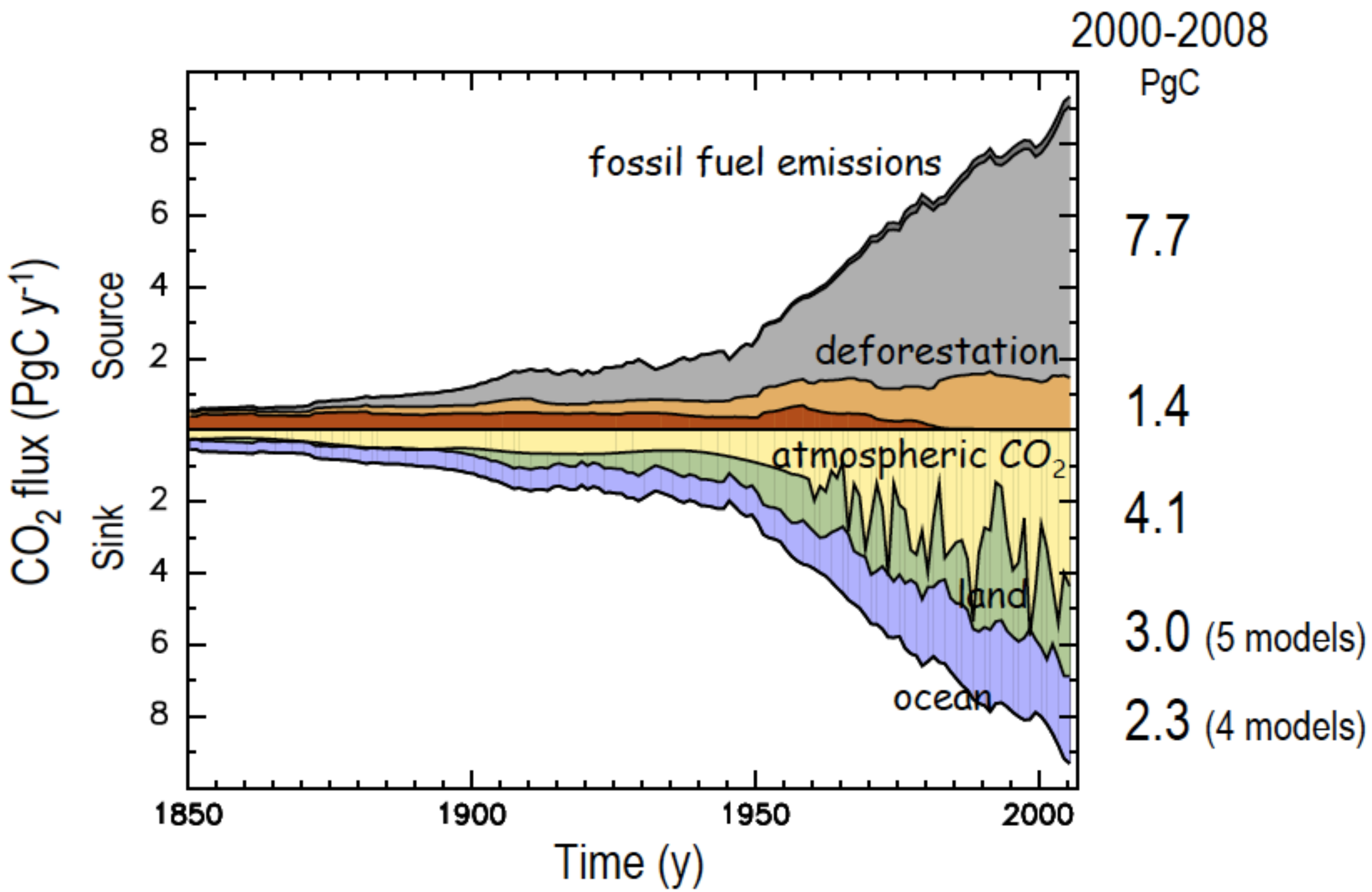
C^{4}MIP models (emission driven)

2.6 – 4.1 °C

2.4 – 5.6 °C

More spread in Temperature (tendancy to increase more), most models predict a positive feedback on temperature (less carbon uptake)

Human Perturbation of the Global Carbon Budget



Global Carbon Project 2009; Le Quéré et al. 2009, Nature Geoscience